IN SITU DEACIDIFICATION OF VERNACULAR WALLPAPER

Kayla Margaret Loveman

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CONTENTS

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INTRODUCTION

Wallpaper is a decorative interior finish that adorned homes of almost all socioeconomic classes by the middle of the 19th century. Higher quality wallpapers from that time period, however, have survived more intact than their less expensive counterparts. Cheaper wallpapers, which were made with wood pulp, have become brown and brittle as a result of acid-catalyzed deterioration, which is less frequently a problem with wallpaper made from more expensive cotton rag. Paper conservators have investigated various deacidification techniques in order to arrest the rate of acid-related deterioration and prolong the life of wood pulp paper that is found in libraries and archival collections. This thesis will investigate whether proprietary deacidification products can also be used to neutralize wood pulp wallpaper *in situ*. If successful, these products may be used by house museums and other lower budget operations in possession of 19th century wood pulp wallpaper to preserve their collections. Testing protocols were established in a laboratory setting and carried out at the Lower East Side Tenement Museum in New York City.

Wallpaper had historically been too expensive for the majority of Americans to afford until the mid-19th century, but with the introduction of machinery to make and print continuous rolls of paper, prices began to drop. It was the introduction of wood pulp, however, which drove prices down so far that wallpaper became popular even among the poorest Americans. Very little has been written about this type of affordable wallpaper from the later half of the 19th century by conservators. It is more ephemeral than higher quality wallpaper and what does remain tends to be very deteriorated and difficult to conserve. In 1869, however, *Manufacturer and Builder* journal declared, "In every mansion, house, and hut in the land, the work of the paper-stainer now confronts the inhabitant."[1] Therefore, it is necessary that conservators consider the wallpaper that hangs in modest dwellings as well as mansions.

Wallpaper deteriorates as the result of its environment and its materials. It is affected by the complex system of the building it is hung in, and the system of the wall it is hung on. As an architectural finish, the temperature, relative humidity, and light infiltration within a building can bleach and embrittle it. Instability in the wall, such as failing plaster or water infiltration can tear and stain it. Wallpaper itself is also a system of several different ingredients that inform its longevity. In the case of wood pulp wallpaper, acids that occur from the presence of wood cause the paper to darken and lose strength over time. Unlike other wood pulp papers such as archival documents, it cannot be protected in a dark, temperature and moisture-controlled storage area. It is a part of the architecture, which makes it more vulnerable and difficult to both conserve and monitor.

Wallpaper can be conserved either in a laboratory or *in situ*. The case could be made for either approach depending on the particular circumstances of any given wallpaper and its environment. Laboratory conservation generally produces better results and allows for better precautions to be taken to preserve the wallpaper in the future. It is also usually a more expensive approach because of the time and labor involved. Laboratory treatment involves the risk of loss of material and damage to the wallpaper during transport. There is also a loss of

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1 "Household Artists," *The Manufacturer and Builder: A Practical Journal of Industrial Progress (1869-1895)*, Vol. 1 no.9 (1869): 279.

architectural context when a finish is removed from its architectural setting. Most importantly, some wallpapers are too brittle to be moved. In these cases, *in situ* treatment is preferable and sometimes necessary.

Deacidification is a conservation technique that was developed by chemists and library and paper conservators as a method to preserve important archival material made from wood pulp. Wood pulp wallpaper, however, exhibits many of the same acid related modes of failure. Wallpaper is often deacidified by paper conservators, using the same methods for individual sheets of paper, only on a larger scale. Deacidification is a technology that has been developing since the middle of the 20th century and today many proprietary deacidification products are available to consumers. This thesis will determine if these products can be used *in situ* on wallpaper that is made of wood pulp, is extremely brittle, and cannot be moved. Deacidification is a term that encompasses neutralization of acids present in the wallpaper and buffering against the future development of additional acid. Before it can be determined if these products can successfully buffer the wallpaper, testing will determine if they can even neutralize it without damaging the visual characteristics of the wallpaper.

Determining the answer to this question began with establishing testing protocols in a laboratory using wallpaper samples presumed to be from the mid-19th century, which were donated by a New York City townhouse that was being gutted. The *in situ* case study was conducted at the Lower East Side Tenement Museum at 97 Orchard Street in New York City. This building was constructed in 1863 and housed low-income, mostly immigrant families and businesses until it was condemned in the 1930s. The term "vernacular" is often used to describe this type of building fabric and it will be used here in reference to the wallpaper found within the building as well.

Three proprietary deacidification products were tested on the wallpaper at the Tenement Museum: Bookkeeper, Wei T'o, and Paper Saver. Paper Saver was determined to be inconsistent and generally ineffective and in some cases, also caused significant changes to the visual characteristics of the wallpapers it was used on. Bookkeeper consistently achieved the highest pH measurements, however, it also caused the most significant changes in appearance. Wei T'o successfully neutralized most wallpaper samples without serious visual alterations. None of the products tested can be comfortably recommended despite the limited success of Bookkeeper and Wei T'o until further research is conducted to determine their long-term effects.

1. THE DEVELOPMENT OF VERNACULAR WALLPAPER

Wallpaper is a decorative material that became popular in Europe during the 16th century as a less expensive alternative to luxury wall hangings such as leather, damasks, silks, and other tapestries.[2] It was, nevertheless, a labor-intensive, high-quality product that was inaccessible to the majority of the population. Wallpaper only became available to most Americans after several technological advancements allowed it to be produced quickly and cheaply.

1.1 Pre-industrial Wallpaper

Both imported and local wallpapers were made by hand until the middle of the nineteenth century. These paper hangings, as they were often called, were imported to the American colonies from England prior to the Revolution, after which French wallpaper became increasingly popular.[3] Papermaking practices of Western Europe were also brought to the American colonies as early as the seventeenth century. Although these techniques varied by region, most notably between Asian and European countries, most European traditions were relatively consistent and were also used by early American papermakers. The materials, time, and labor required to make pre-industrial wallpaper resulted in an expensive product.

1.1a Papermaking

The primary material of any paper before the middle of the nineteenth century was rag, usually of cotton or linen. Rags were turned to pulp by stamping and fermenting torn cloths in basins filled with water, chalk, and soda. Once the fabric had become sufficiently macerated, which took approximately one month, it was combined with water in a dipping vat. A "vatman" would then lower a mold into the vat and gather the pulp in an even layer on the mold's surface, shaking it in various directions to expel excess water and crisscross the fibers to make the paper more durable.

The next workman, known as the "coucher," would then release the mold from its removable frame and adroitly flip the still-wet paper from its mold onto a piece of felt. After a stack of 144 sheets of paper interspersed with layers of felt had been assembled, the stack was pressed to expel still more water.

The compressed stack was then passed along to the "layman," who separated the paper from the felt, restacked the paper, and pressed it again. The layman would rearrange the 144 sheets of paper and press them repeatedly until they were satisfactorily dry, at which point the paper was hung in small groups together to dry completely without wrinkling. Once the paper had dried, individual sheets were often dipped in size and their surfaces

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2 Catherine Lynn, *Wallpaper in America: From the Seventeenth Century to World War I* (New York: Norton, 1980), 17.
3 Richard C. Nylander, "An Ocean Apart: Imports and the Beginning of American Manufacture," In *The Papered Wall: History, Pattern, Technique* (New York: Harry N. Abrams, 1994): 114.

were finished by various methods, according to their intended use.

This process, which required hard and skilled labor, could take months to produce a single sheet of paper. In addition to the vatman, coucher, and layman, additional laborers were also necessary prior to the introduction of machinery. Before the invention of a mechanized agitator, for example, a worker was employed in stirring the dipping vat to prevent the pulp from settling to the bottom.[4] The lack of machinery also limited the dimensions of paper and therefore the complexity of the wallpaper design. A single sheet of paper could not exceed the size of the mold a vatman could handle, which was usually no larger than thirty-two inches in length.[5] Early wallpaper consisted of several of these single sheets of paper that were also hand-painted or printed, which added to the time and energy required to manufacture pre-industrial wallpaper.

1.1b Printing

Some of the earliest wallpaper was produced by London stationers who were involved in the hand-manufacture of a variety of paper products. Stationers would print single sheets of paper with carbon black, which was sometimes followed by colored paint or stenciling once the black ink had dried.[6] These early "lining papers" were used to decorate the insides of trunks and drawers and were also commonly pasted directly onto walls. The most common method of printing stationers' lining papers was by screwing wooden blocks with the intended design into a table and using a roller or mallet to impress the design onto a piece of paper laid on top of the wood block.[7] The original ink used was printer's ink, which was made of pigment mixed with walnut oil and turpentine. Varnish, animal glue, and gum were also common constituents of early printer's ink, which is a very stable material.[8] Distemper paints were adopted for paper production by the 17th century, which were made of a pigment and binder, usually gelatin, along with whiting, size plant gum, and casein as additives.

In France, wallpaper tradition began with what was perhaps the first vernacular form of wallpaper. Dominoes were single sheets of paper that were decorated with religious scenes and pasted directly to a wall. Dominoes were popular beginning in the 16th century, but as religious fervor began to fade and the ideals of the Renaissance became more popular in France, dominotiers began to portray secular themes instead. One contemporary notes that dominoes "had long been used only by country folk and the lower classes in Paris to decorate and, so to speak, 'hang' certain parts of their huts, shops, and rooms."[9]

The upper class alternative to dominoes was *papier de tapisserie*, another early single-sheet wallpaper in

4 This account of the papermaking process comes primarily from Dard Hunter's 1943 book *Papermaking: The History and Technique of an Ancient Craft*, which highlights the history of papermaking in general, not necessarily wallpaper in particular.
5 Lynn, *Wallpaper in* America, 32.
6 Anthony Wells-Cole, "Flocks, Florals and Fancies: English Manufacture 1680-1830," In *The Papered Wall: History, Pattern, Technique* (New York: Harry N. Abrams, 1994), 22.
7 Geert Wisse, "Manifold Beginnings: Single-Sheet Papers," In *The Papered Wall,* 17.
8 Paul Thomas Mann, "Wallpaper Preservation: A Field Guide for the Architectural Conservator" (Masters thesis, Columbia University, 1997), 24.
9 Jacques Savary des Bruslons, *Dictionnaire Universal du Commerce,* 1723, quoted in Geert Wisse.

France, which was common by about 1700. These were higher quality and better-designed papers than dominoes and were popular among the higher social classes. The designs were sometimes individual to a single sheet of paper, and sometimes they were part of a larger design scheme that many of these papers could evoke together.[10]

The final step in the traditional wallpaper process was the actual application of the paper to the wall. Like the papermaking and printing processes that preceded it, paperhanging was a very labor-intensive process that required a certain amount of training and skill to do properly. The paper needed to be smoothed before it was applied to the wall and the wall itself was prepared for each individual sheet using a plumb line.[11] In 1856, James Arrowsmith wrote *The Paper-Hanger's Companion* to serve professionals hanging wallpaper. In the introduction to the manual, Arrowsmith laments the general public's misconception about the ease of wallpaper hanging.[12]

It is easy to understand why, then, wallpaper remained so expensive and out of reach for most people despite it being considered a cheap alternative to textiles, given the amount of time, work, and the quality of materials required to produce it.

1.2 Mechanization, Continuous Rolls

The first major step toward universal access to wallpaper was the mechanization of both making and printing paper. Mechanization not only significantly reduced the time and labor required for paper production, but developments in machinery led to the crucial creation of continuous rolls of paper, which made producing, printing, and hanging wallpaper significantly cheaper and easier. Most of these developments were invented in England and France and were soon adopted by American wallpaper manufacturers.

1.2a Papermaking

Even before mechanized papermaking, paper-stainers, or early wallpaper manufacturers, recognized the need for continuous rolls of paper. As early as 1699, stationers in London glued single sheets of paper together to make longer rolls that were then block printed and colored with brushes.[13] This practice, which was soon adopted by American paper-stainers, enabled the wallpaper industry to take off as its own unique enterprise, separate from the rest of the paper trades. With joined rolls of paper, which were typically 12 yards in length, paper-stainers could fabricate convincing imitations of fine textiles that became very popular.[14] Stenciled and block printed wallpapers could be made to look like oriental chintzes, while flocked papers emulated velvets,

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10 Wisse, "Manifold Beginnings," 17.
11 *Ibid*.
12 James Arrowsmith, *The Paper-Hanger's Companion: A treatise on Paper-Hanging,* (Philadelphia: Henry Carey Baird, 1856).
13 Wells-Cole, "Flocks, Florals, and Fancies," 22.
14 Nylander, "An Ocean Apart," 122.

damasks, and brocades.[15] The glued seams of these hand-joined rolls, however, often pulled apart under the pressure of printing machines.[16]

Papermaking machines capable of creating continuous rolls were first patented in England at the turn of the nineteenth century. The first of these, the Fourdrinier machine, was patented in England originally in 1799 and was first imported to the United States in 1827.[17] Capable of making 27'x4' rolls, the Fourdrinier and other machines like it, fuelled a boom in the wallpaper industry.[18] The period between 1820 and 1840 is generally regarded to be one of transition in the manufacture of wallpaper, when a gradual shift was made from hand production to machine production.[19] By the mid-1850s, manufacturers had almost universally adapted industrial papermaking processes and began to search in earnest for additional ways to cut costs.[20]

1.2b Printing

In addition to creating continuous paper rolls, it was also necessary to be able to dry and print them quickly in order to actually lower prices. The technique of passing rolls of wallpaper through a chamber heated by steam pipes was employed by companies such as J.R. Bigelow's Paper Hangings Manufactory in Boston, Massachusetts to dry the paper faster. Before this method was developed, simply hanging the paper to dry created expensive delays in production.[21] Timesaving techniques such as this were developed during the mid 19th century as mechanized printing and papermaking technology evolved simultaneously.

Printing machines were used on paper products beginning in the 1820s to apply ground layers and simple stripes.[22] This early printing technology, however, proved difficult to apply to wallpaper manufacture. In addition to pulling apart the seams of hand-joined rolls, designs were difficult to register and the paint was often blurred[23] Early cylindrical presses were made with copper engraved rollers, which could not impart a clear impression of the intended design using the thick distemper paints that were common on wallpaper.[24] In 1827, the Zuber factory in Alsace, France began to use a thin colored varnish rather than distemper, which made it possible to apply fine detail with the engraved copper rollers.[25] By the 1840s, machines used for applying ground color and stripes had been effectively adapted for use on wallpaper and were commonly used in the United States, first powered by horses and then with steam.[26] Once manufacturers had resolved early problems associ-

15 *Ibid.*
16 *Ibid,* 24.
17 Lynn, *Wallpaper in America,* 301.
18 Joanna Banham, "The English Response: Mechanization and Design Reform" In *The Papered Wall,* 134-5.
19 Lynn, *Wallpaper in America*, 302.
20 *Ibid.*
21 J. Leander Bishop, *A History of American Manufacture From 1608 to 1860,* vol. 3, (Philadelphia: Edward Young & Co., 1868): 306.
22 Lynn, *Wallpaper in America,* 305.
23 Banham, "The English Response," 136.
24 *Ibid*, 135.
25 Lynn, *Wallpaper in America,* 307.
26 Nylander, "An Ocean Apart," 130.

ated with machine printing, they began to focus on how to successfully apply more than one or two colors at a time.[27]

The first commercially successful multi-colored steam printer was invented in England in 1839 using raised, rather than engraved wooden surfaces, similar in principle to traditional block printing.[28] Three years later, the first mechanically printed American wallpaper was produced in Philadelphia by the firm Howell & Brothers.[29] By the 1860s, cylinder presses that could print up to twenty colors at once were used for printing inexpensive wallpaper.[30]

Mechanization enabled the reduction of time, labor, and costs associated with production that led to the precipitous growth of the early wallpaper industry. In 1868, an article that appeared in *A History of American Manufacture* stated that "the modern application of machinery in the various processes, which has so cheapened the product that it is now possible for the humblest citizen to ornament his dwelling as handsomely, and with the moiety of cost, as a noble man was able to do two hundred years ago."[31] It was the introduction of wood pulp, however, that truly allowed the industry to proliferate.

1.3 Wood Pulp

By the mid-nineteenth century, rags for papermaking had become scarce and expensive. Consumption of paper for books, newspapers, and magazines increased dramatically in the early 18th century, making raw materials increasingly unavailable.[32] Manufacturers of wallpaper, as well as other paper products, were forced to search for alternative ingredients. Newspaper companies, in particular, briefly experimented with plant fibers such as straw and hemp until wood pulp became economically viable. This introduction of wood pulp to the American papermaking industry in 1855 was one of the most significant developments that led to the nearly universal availability of wallpaper.[33]

The most common wood species for wood pulp paper production were spruce, balsam, fir, jack pine, hemlock, southern pine, poplar, and cottonwood. Spruce was favored because of its light color and strong fibers, followed by hemlock. Unlike the machinery that was introduced to the United States from England, wood pulp technology initially came from Germany. The first commercially successful manufacture of wood pulp in the U.S. began in 1867 near Stockbridge, Massachusetts by Albrecht Pagenstecher, whose methods were based on original1840s German patents.[34] Pagenstecher, along with other early manufacturers of wood pulp, produced ground-wood pulp using a revolving wet grindstone. This mechanically ground wood pulp, although very inex-

27 Banham, "The English Response," 136.
28 Lynn, *Wallpaper in America*, 307.
29 Nylander, "An Ocean Apart," 129.
30 Manufacture and Builder 1869
31 Bishop, *A History of American Manufacture*, vol. 3, 305.
32 Dard Hunter, *Papermaking: The History and Technique of an Ancient Craft*, (New York: Dover, 1978): 309.
33 Lynn, *Wallpaper in America,* 302.
34 Hunter, *Papermaking,* 377-8.

pensive, was not very durable, as demonstrated by early wood pulp newsprint, which was the least durable 19th century paper. It was soon discovered that wood pulp needed to be purified of its lignin in order to slow the rate of paper deterioration, which was accomplished by various chemical processes.[35]

Although chemically processed pulp was more durable, and therefore more expensive than groundwood pulp, it was still a cheaper raw material than rag. Soda pulp, which was developed in England in 1851, was the first chemically processed wood pulp. It was made by boiling wood chips in caustic alkali under conditions of high pressure and temperature. The fibrous mass was then washed with water, and chlorine if resin was present in the pulp. Some mills chose not to use resinous woods in order to eliminate the need for the extra step of washing wood with chlorine, which could weaken the pulp. Poplar and hemlock were popular choices for soda pulp because they were non-resinous, light colored, and not particularly valuable for any other use either, making them easily affordable and accessible.[36]

The sulfate process, more commonly known as the Kraft process, grew out of the soda process beginning in 1870 and is still in use today. The Kraft process uses sodium sulfate, rather than the sodium carbonate used in soda pulping, which creates better delignification and a higher-quality pulp.[37]

Another common chemical process for making wood pulp was the sulfite process, which used acid rather than a base in order to extract lignin from cellulose. It involved pressurized calcium hydrogen sulfite and sulfur dioxide and a counter ion. First patented in the United States by Benjamin Tilghman in 1866, the sulfate process was not commercially adapted in the United States until European scientists had perfected it by the late 1880s.[38] Because the strong acids used in sulfite pulping can hydrolyze cellulose, it creates a less durable pulp than the Kraft process.

The newspaper industry was the most obvious beneficiary of wood pulp for papermaking and the information available about wood pulp is provided by statistics from newspapers more than the wallpapers industry. Although newspapers did not initially adopt wood pulp because of quality issues, they soon realized that it made good paper for printing on and could significantly lower their production costs.[39] In the 1860s, before wood pulp was introduced, the cost of newspaper paper was twenty-five cents per pound. Ground-wood drove the price down to as low as one cent per pound.[40]

Once wood pulp and other inexpensive fibers such as straw, esparto, and reeds began to be used for the manufacture of wallpaper, it became an easily accessible product even for Americans living in tenements. With prices starting at 4.5¢ per roll in 1898, an entire tenement apartment could be papered for less than \$1.[41] Even

35 Hunter, *Papermaking,* 389.
36 *Ibid,* 390.
37 Eero Sjösström, *Wood Chemistry: Fundamentals and Application, Second Edition,* (New York: Academic Press, Inc., 1993), 116.
38 Hunter, *Papermaking*, 392-392.
39 *Ibid,* 378.
40 *Ibid,* 390.
41 Andrew Dolkart, *Biography of a Tenement House in New York City* (Santa Fe: Center for American Places,

the most inexpensive wallpapers were printed with the most popular styles, according to an 1884 edition of Carpentry and Building: "It is quite remarkable how quickly the supply for cheap and truly artistic papers has responded to the demand."[42] Wallpaper, therefore, became a very popular interior finish in the homes of the working poor across the country.

2007), 65.

42 Joanne Kosuda Warner, "Proliferation: Late 19th-Century Papers, Markets and Manufactures," In *The Papered Wall*, 173.

2. DETERIORATION

2.1 External Threats

Wallpaper, as an architectural element, is exposed to more potentially destructive conditions than other papers intended for permanent use. Most other permanent paper from the nineteenth century was produced for archival material or works of art, and therefore more consideration has typically been given to its protection. Wallpaper, however, is exposed to a more open and vulnerable environment. Rather than benefiting from the protection of a binding or a frame, or even storage, wallpaper must endure light exposure, fluctuations in relative humidity and temperature, and atmospheric contamination without any safeguard of its own.

Wallpaper is also a part of larger systems that affect its longevity. If any one part of the architectural or wall system it belongs to fails, the wallpaper is put at risk of sharing in that failure. Cracking, buckling, or crumbling of the wall may tear the wallpaper on the surface and water infiltration within the wall or other adjacent building elements will stain it, promote mold growth, or dissolve the paste that binds the paper to the wall. Substrate material may also affect the longevity of wallpaper even without failure, especially when it is adhered directly to the wall without a lining cloth. Plaster walls are generally alkaline, which may protect wood pulp wallpaper from acid-catalyzed degradation for a certain period of time, but may threaten the integrity of cotton-based wallpaper. Wooden walls can cause a significant amount of damage to any type of wallpaper. Expansion and contraction due to changes in relative humidity may tear the wallpaper and its hygroscopic nature can dry it out, making it more brittle. Wood is also more acidic than plaster, which is particularly harmful for wood pulp wallpaper.

Exposure to ultraviolet and incandescent light acts as an external threat to the durability of wallpaper. Not only does light cause degradation of visual characteristics, such as fading, it can also oxidize cellulose and cellulose byproducts such as lignin.[43] Oxidation causes cellulose to release carbonyls and carboxylic acids, which will hydrolyze the cellulose and causes discoloration with the presence of hemicelluloses, lignin, and alum-rosin sizing.[44] As an architectural finish, wallpaper is constantly exposed to light.

Relative humidity and temperature are also major external concerns for the longevity of wallpaper.[45] If relative humidity falls too low, the wallpaper will dry out and become brittle, and if its moisture content is too high, it can foster mold growth or swell a wooden substrate. Wallpaper in a high RH environment also has more water molecules to potentially hydrolyze cellulose polymers. Temperature is inversely related to relative humidity and extreme temperature fluctuations must therefore be avoided to prevent fluctuations in moisture. Paper always deteriorates more rapidly as the temperature increases.[46]

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43 Maravilla, Nimfa R., "Causes of Deterioration of Paper," *CoOL*, http://cool.conservation-us.org/byauth/maravilla/deterioration-causes.html.

44 "Oxidation of Cellulose," http://www.conservationresources.com/Main/S%20CATALOG/Oxidation%20of%20Cellulose.htm.

45 B. L. Browning *Analysis of Paper* (New York: Marcel Dekker, 1977), 316.

46 *Ibid,* 319.

Finally, an additional source of soiling and acid is introduced to the wallpaper in the form of atmospheric contaminants. Sulfur dioxide, particularly, oxidizes free sulfuric acid when absorbed by the wallpaper.[47] Again, any of these factors can affect other forms of paper other than wallpaper, but wallpaper is at a higher risk of encountering them because of its continually exposed state.

2.2 Internal Threats

Wallpaper itself is also a complex system of materials. Most wallpaper consists of paper, size, a ground layer of paint, additional decorative paint layers built up on top of the ground layer, and some sort of adhesive to adhere it to the wall, usually wheat paste. More elaborate wallpapers include additional materials, such as flocked wallpaper, which was varnished and dusted with cotton and/or wood pulp to create a textured design. The paper itself was made primarily of cotton or wood pulp during the 19th century.

Acid-related deterioration of wallpaper can result from a variety of sources, including certain inks and adhesives, lining papers, residues of bleach or pulping agents, and atmospheric contaminants. Paper made with wood pulp tends to deteriorate as a result of acid at a much faster rate than paper made with rag pulp. Perhaps the most significant source of acid in wood pulp paper is the presence of alum, which is used in the papermaking process for rosin sizing. Sulfuric acid is produced when alum hydrolyzes, which in turn hydrolyzes cellulose.[48]

Cellulose fibers, which are present in both wood and cotton, are more likely to de-polymerize in wood pulp than in cotton rag because of the industrial processes required to convert wood to wood pulp and because of the presence of additional fibers in wood, particularly lignin, which are not found in cotton. These factors result in an increased amount of acid in wood pulp paper, which catalyzes the breaking of cellulose chains, as well as lignins and hemicelluloses. It is this scission of cellulose polymers and to some extent other fibers that results in paper losing strength over time, which is characteristic of wood pulp paper.[49]

Cellulose, hemicelluloses, and lignin are the three principal fibers found in wood.[50] Of the three, cellulose is the only one that is desirable for the production of permanent paper and it is the destruction of cellulose that is the primary cause of paper failure. Cellulose is a long-chain, crystalline D-glucose molecule that provides strength to wood's cell structure as well as to paper products.[51] Hemicelluloses, which usually consist of several different sugar monomers, are weaker than cellulose because of their random molecular content and structure, and are therefore much more easily hydrolyzed.[52] The presence of acidic hemicelluloses in wood pulp also makes the

47 *Ibid,* 169

48 Browning, *Analysis of Paper,* 169.

49 Ritzenthaler, *Preserving Archives and Manuscripts,* 346.

50 Sjostrom, *Wood Chemistry,* 292.

51 Bruce Hoadley, *Understanding Wood* (Newtown, CT: Taunton, 2000), 10.

52 Charles Tumosa, David Erhardt, Kathy Hufford, and Evan Quasney, "The Deterioration of Newsprint and Implications for its Preservation," *WAAC Newsletter* Vol 30 no. 3 2008, 22. http://cool.conservation-us.org/waac/wn/wn30/wn30-3/wn30-305.pdf.

cellulose less stable.[53] Lignin is the most complex and least understood of these three fibers. If the deterioration of wood pulp paper is not completely understood, it is because lignin itself is not completely understood. While lignin adds strength to cellulose in nature, it tends to destroy cellulose in paper, possibly because its molecular form changes when it is removed from wood.[54] Although types of lignin differ by a tree's species, almost all lignins produce carboxylic acids when they deteriorate, which can hydrolyze cellulose fibers.[55]

Paper from the nineteenth century made of mechanical or groundwood pulp, in which lignin is left intact, such as newsprint, is one of the most problematic types of paper. Lignin began to be removed from paper pulp by chemical processes beginning in the mid-19th century in order to prevent degradation that is characteristic of newsprint. Chemical pulping not only purifies cellulose of much of its lignin, it also allowed cellulose fibers to retain their length, which was not possible with ground-wood, and which creates a more durable product. These chemical processes, however, can seriously damage the integrity of cellulose chains and residual acidic pulping agents will damage the paper in the future.

Acid-catalyzed hydrolysis is the most pressing concern for cellulose fibers in wood pulp paper. As paper chemist B. L. Browning described it, "acid hydrolysis leads to degradation of the cellulose by scission of the chains of anyhydroglucose units and causes tendering of the fibers and weakening of the fiber bonds."[56] Cellulose constitutes approximately half of the makeup of wood, as opposed to approximately ninety percent of cotton, and therefore chemically produced wood pulp requires more aggressive purification processes than cotton in order to remove non-cellulosic material.[57] These processes can damage cellulose fibers, making them more susceptible to de-polymerization. Many chemical pulping processes, such as the still-in-use Kraft process, employed alkaline solutions to purify cellulose of its lignin. Others, such as the sulfate process, used acids to achieve the same outcome. In either case, the cellulose is weakened. When acids are used as pulping agents, however, any residual acidic material will threaten the durability of the paper. Bleaching the pulp with chlorine, which further weakens cellulose fibers and adds another source of acid to the paper stock, often followed chemical pulping processes.[58]

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53 Browning, *Analysis of Paper,* 317.
54 Hoadley, *Understanding Wood,* 10.
55 Ellen McCrady, "The Nature of Lignin," *Alkaline Paper Advocate*, Vol. 4 no. 4, Nov 1991. http://cool.conservation-us.org/byorg/abbey/ap/ap04/ap04-4/ap04-402.html.
56 Browning, *Analysis of Paper,* 170.
57 *Ibid*, 317.
58 Diane Vogt-O'Connor and Dianne van der Reyden, "How to Preserve Acidic Wood Pulp Paper," *Conserve O Gram* vol 19 no. 24, 2001.

3. DEACIDIFICATION

Wallpaper is an important, yet ephemeral architectural finish. In many cases, it speaks to the tastes and status of its owner more than paint can, which is a compelling argument for its preservation. Unfortunately, most of the wallpaper from the 19th century has been lost and any conservation work that has been done on wallpaper from that era has been directed toward high-end wallpaper. No doubt the work of these conservation projects contributes to the body of knowledge in paper, wallpaper, and architectural conservation. It also, however, deals with a different set of issues than those that are most pressing with wood pulp wallpaper. This thesis topic was originally chosen in order to determine if the lifespan of wood pulp wallpaper common in more vernacular buildings could be extended by the use of relatively affordable and easily applied proprietary deacidification treatments. It has since become focused specifically on determining whether select deacidification products will even work initially *in situ*, and is therefore not an investigation of how wallpaper will perform in the future after treatment. Nor is the scope of this thesis to restore the wallpaper to its original condition, but rather to slow the rate of deterioration by neutralizing harmful acids. It is left to further research to determine if successful neutralization will in fact extend the lifespan of wood pulp wallpaper.

3.1 Development of Deacidification

Deacidification techniques were originally developed for the conservation of important paper documents and books. Acid-catalyzed destruction of cellulose fibers is the most common cause of paper deterioration, such as discoloration and embrittlement, which can be countered and prevented in the future by deacidification.[59] The term “deacidification” has been applied to alkaline washing, neutralization, or alkalization, which is sometimes referred to as “buffering,” of acidic paper. In the case of neutralization, alkaline agents react with acids in paper to form a salt.[60] Alkalization or buffering goes a step further by depositing an alkaline reserve in the paper in order to neutralize acids in the future. Deposition of too much alkaline reserve, however, can cause the cellulose to oxidize, so a pH of over 8 is to be avoided. Deacidification technology has been developing in this country since the 1930s, beginning most notably with research conducted by William J. Barrow at the request of the Council on Library Resources.[61] Since then, many deacidification patents have been registered, employing a vast range of deacidification agents and solutions.

The three most common modes of deacidification that have been developed are by aqueous, non-aqueous, and vapor methods. Vapor methods, however, have proven to pose health hazards without any significant lasting effects and will not be considered here.[62] Aqueous deacidification methods tend to be the most effective of the three because they wash away acidic water-soluble deterioration product, however, they have their own set of limitations. In addition to being very labor intensive and therefore expensive, aqueous deacidification can also only be performed on single sheets of paper. Bound materials such as books cannot be deacidified by aqueous

59 Mary Lynn Ritzenthaler, *Preserving Archives & Manuscripts, Second Edition* (Chicago: Society of American Archivists, 2010), 346.
60 Randall Couch, “Neutralization and Alkalization,” *Paper Conservation Catalogue, Second Edition*, 1985 1.
61 Ritzenthaler, *Preserving Archives & Manuscripts,* 347.
62 *Ibid,* 349.

methods without each sheet being removed from its binding. Aqueous deacidification is also inappropriate for paper containing water-soluble paints or inks.[63] Many wallpapers are printed with distemper paint, which is a water-soluble material that would be destroyed by aqueous deacidification and they are often bound to the wall with a water-soluble paste.

There are several aqueous methods, most notably the "Barrow two-step process", as well as the original one-step process. The first involves washing the paper in a water bath and then immersing it in a saturated solution of calcium hydroxide at a pH of 11 to 12. Calcium hydroxide neutralizes acid in the paper and also deposits carbonates to protect against future acids. Many stains are soluble at such a high pH, which can improve the overall appearance of the treated paper. The one-step method involves soaking the paper in a single solution of magnesium bicarbonate, which also protects against future deterioration.[64]

Non-aqueous deacidification, which employs organic solvents rather than water, was developed to treat materials that cannot be subjected to aqueous treatment such as books, which have hydrophilic bindings that are destroyed by water. Just because a deacidification process is non-aqueous, however, does not indicate that it will not harm the paper. Although distemper paints were commonly used for printing wallpaper, other materials, such as casein paint or shellac and varnish used for flocking are solvent soluble. Complications associated with non-aqueous solutions include toxicity, odor, residual surface deposits, color changes to paper and media, cost, and an inability to achieve a proper alkaline reserve.[65] There are many patented non-aqueous deacidification products available on the market that vary in formulation, effectiveness, and the amount of harm they can cause to the paper.

Deacidification is only one of many methods conservators utilize to treat paper that has been damaged over time and to protect against future damage. Because it is an irreversible and aggressive approach that poses many risks to the paper being treated, it should only be used once other less potentially destructive options have been ruled out. Controlling environment, i.e. temperature, relative humidity, and light exposure, is preferable to deacidification in most cases, but it is much more difficult to accomplish with *in situ* wallpaper than with archival collections. The environment in wallpapered rooms should always be controlled as much as possible but because of the scale and complexity involved, deacidification may also be considered in order to prolong the lifespan of the wallpaper.

3.2 Differing Opinions

Deacidification used to be one of the most commonly used techniques in paper conservation.[66] There are, however, differing opinions among conservators about the effectiveness of deacidification on the long-term preservation of wallpaper. Today, deacidification is almost exclusively carried out for the preservation of library collections. Very little has been written about the deacidification of wallpaper, or more specifically, on the *in situ*

63 *Ibid*, 347.
64 *Ibid*, 348-9.
65 Martina Cedzová, Ingrid Gállová and Svetozár Katuscák, "Patents for Paper Deacidification," *Restaurator* vol. 27 no. 1, 2006, 2.
66 *Ibid.*

deacidification of wallpaper. Accelerated aging tests have suggested that deacidification treatment can result in the loss of mechanical strength over time. Excess alkalinity can damage cellulose chains as dramatically as excess acidity and may also result in an increased uptake of pollutants, causing the paper to become more brittle than untreated paper.[67] Deacidification may also cause significant changes to the appearance of the treated paper, particularly in the case of nonaqueous products.

In her 2002 Columbia University Historic Preservation master's thesis, Katharine Morrison Danzis stated "there are not any completely satisfactory procedures that can be used to fully address this problem (acid) without removing wallpapers from the wall."[68] She mentioned Wei T'o and Bookkeeper, both products being tested for this thesis, as effective products for neutralizing acid in paper but also warned that they negatively affect the visual characteristics of wallpaper and should therefore not be used *in situ*. While it is true that non-aqueous deacidification products may alter the look of paper products, no testing has ever been carried out in order to confirm that these proprietary deacidifyers are inappropriate *in situ* treatments for wallpaper. These products have also been reformulated in the decade since Danzis's thesis was completed.

While many conservators are concerned about the negative effects of deacidification, others doubt the need for its use to begin with. Some conservators maintain that acidity in wallpaper is not, in fact, the most pressing concern. When asked for advice in the early stages of research for this thesis, esteemed conservator Allyson McDermott explained that acidity in wallpaper was rarely a contributing factor in its deterioration. She noted that several components in the wallpaper system, including alkaline paints that are used for the ground material and alkaline fillers, buffer the paper themselves. Proximity to plaster walls, particularly those rich in lime also provides a source of alkalinity. In her experience, excess alkalinity is more often a problem than excess acidity in historic wallpapers"[69] Ms. McDermott does, of course, make a valid argument about the several sources of alkalinity that wallpaper may benefit from, but she is speaking from experience as a highly regarded conservator of more expensive wallpaper, which is produced with better materials and generally hung under more cautious conditions. Very little of her work involves mass-produced wood pulp vernacular wallpaper.

Other conservators, mostly located in Eastern Europe, maintain that the successful neutralization of acids, and ideally alkalization or buffering, can prolong the lifespan of wood pulp paper. Although deacidification can often be avoided in some permanent papers by changing their environment to a darker repository with controlled temperature and relative humidity, it cannot always be the only solution for wallpaper that remains *in situ*. Deacidification may pose risks for the condition of the wallpaper in the future, but not treating it is also a risk because the feedback loop of autocatalytic destruction will continue uninterrupted.[70] Specific testing of deacidification products on wallpaper *in situ* has never been conducted and written about. Before it can be determined

67 Couch, "Neutralization and Alkalization," 1.
68 Katharine Morrison Danzis, "In-situ Conservation of Wallpapers: Treatment Methodologies and the Consolidation of Powdering and Cleaving Paint," Columbia University Historic Preservation Masters Thesis (New York), 2002.
69 Allyson McDermott, email correspondence, December 21, 2011.
70 "An Evaluation of the BookKeeper Mass Deacidification Process: Technical Evaluation Team Report for the Preservation Directorate," Appendix E, *Library of Congress, 1994.*

what will happen to wood pulp based wallpaper when deacidification is performed *in situ*, it must be determined if the wallpaper can even successfully be neutralized without being destroyed.

3.3 Products Tested

Only non-aqueous treatments were selected for testing because of the probable water solubility of the materials involved, including the paste and paint. Aqueous solutions may be carefully applied to the reverse side of wallpaper in a laboratory setting, but should not be used *in situ*, where only the front surface is exposed to the treatment. Three commercially available proprietary spray products were chosen because they are easily accessible and relatively inexpensive, both of which are important considerations for small budget house museums. A proprietary Italian product that is not available in the United States was also tested because it was made available by a member of the Columbia University Historic Preservation faculty. Proprietary deacidification products are constantly being reformulated to meet toxicity regulations and improve such qualities as penetration, evenness of application, and visual alteration. The organic solvents used in non-aqueous solutions can be dangerous to the person administering them and therefore a respirator should be worn at all times when handling.

One of the earliest non-aqueous products, Wei T'o, was developed by Dr. Richard Smith during his PhD research at the University of Chicago in the 1960s, using magnesium methoxide as the deacidifying agent. Magnesium hydroxide and carbonate were initially formed by this product, which neutralized the acid. Basic magnesium carbonate was subsequently formed by magnesium hydroxide's interaction with carbon dioxide, oxygen, and water from air, which served as an alkaline reserve. Wei T'o was the first commercially available nonaqueous deacidification product and has been used in spray form by such institutions as Princeton University Libraries and the British Library. Dr. Smith subsequently developed a mass deacidification system in addition to many other individual spray products with different solvents and deacidification agents since its first product, which included toxic Freon among its ingredients. In recent years Wei T'o used methoxy magnesium methyl carbonate (MMMC), which was invented by the Library of Congress, as the deacidifyer. MMMC also reacts with moisture and air to create magnesium carbonate. The particular product being tested is Good News Spray No. 111 with ethoxy magnesium ethyl carbonate (EMEC) as the deacidification agent. Wei T'o states that it will soon phase out #111 and replace it with an improved product later in 2012; Dr. Smith believes this new product will be more suitable for deacidifying wallpaper *in situ*.[71]

Bookkeeper® is another nonaqueous deacidification product available for both mass deacidification and individual treatment. The Bookkeeper patent was originally awarded to a chemical company called Koppers Company, Inc. in 1985, and was sold to the founder of Preservation Technologies Limited Partnership (PTLP) in 1990.[72] Magnesium oxide is the deacidification agent in the Bookkeeper process, which is converted to magnesium hydroxide by a reaction with water molecules. PTLP was the sole respondent to an RFP issued by the Library of Congress in 1993 after it had discontinued the use of diethyl zinc (DEZ) for the mass deacidification of its own collection. Bookkeeper was tested and analyzed by the Preservation Directorate at the Library of Congress, which determined that "accelerated aging tests and folding endurance measurements showed a signif-

71 Dr. Richard Smith, email correspondence, April 1, 2012.

72 Dennis C. Tucker, *Library Relocations and Collections Shifts* (Medford: Information Today, 1999), 59-60.

icant decrease in the rate of paper degradation as a result of the treatment." There were also, however, negative characteristics observed by the conservators at the Library of Congress, including the deposition of magnesium oxide on the surface of the paper, the formation of a visually distracting white haze, poor penetration qualities, uneven distribution of the deacidifyer, a chalky feeling on the surface, and an inability to treat older, more acidic books as successfully as test samples.[73] Bookkeeper was deemed a successful deacidification process according to the guidelines set by the Library of Congress and continues to be used by the LOC today.

PaperSaver®, which was developed by the Berkeley, California chemical company Provenance, is the most recent and least expensive deacidification product. Like Bookkeeper, PaperSaver also uses magnesium oxide as the deacidification agent, however, unlike Bookkeeper, it claims to only require application to one side of a piece of paper, which is useful for *in situ* wallpaper.

Nanorestore® uses nano-sized particles of $Ca(OH)_2$ in isopropyl alcohol and distilled water and is brushed, rather than sprayed, onto the wallpaper samples being treated. This product was developed at the University of Florence and is not available for sale in the United States because it is too volatile. Calcium hydroxide has been used in paper deacidification since the 1930s, however, the use of nano-sized particles of lime is only just beginning to be explored by conservators, mostly for works of art.

73 Sarah Stauderman, Irene Brückle, and Judith J. Bischoff, "Observations on the Use of Bookkeeper Deacidification Spray for the Treatment of Individual Objects," *The Book and Paper Group Annual*, vol. 15, 1996.

4. DEVELOPING TEST PROTOCOLS IN THE LABORATORY

Testing protocols for *in situ* deacidification were initially developed in a laboratory using fragments of wallpaper that had been removed from a townhouse at 109 Waverly place in New York City. This particular wallpaper, which is assumed to be from the mid-19th century, was most likely not the lowest grade possible given the presence of cotton fibers, its relatively neutral starting pH, and the fact that most of it was not very brittle. It was still, however, useful in creating a testing protocol and in determining if the selected deacidification products increased pH or if they caused harm to the wallpaper. Testing data and images from laboratory testing may be found in Appendix A.

Using wallpaper from the same room of the same house was done with the intention of eliminating variables. It soon became apparent, however, that this wallpaper was not uniform in condition and had its own set of variables. Although it was fabricated from the same materials and hung in the same room, its visual and mechanical characteristics varied widely within a small area. All of the wallpaper was somewhat soiled, but some areas had dramatically darkened while others appeared bleached. The reverse side of the sample had blackened or included a layer of paint in some areas and not in others. Brittleness also varied within the sample, with washed out areas the easiest to tear during pH testing preparations. To initially establish if acidification could be a deterioration mechanism of the wallpaper, wood pulp needed to be identified among its components.

Figure 4-1: Laboratory samples exhibited different amounts of soiling


Figure 4-2: Reverse side of laboratory samples also exhibit differing conditions


Figure 4-3: The pattern appears different under different soiling conditions


Figure 4-4: Paint was found on the reverse side of some areas of the samples

4.1 Wood Pulp Identification

Wood fiber should be identified to determine whether the paper is made from wood pulp. Without the presence of wood pulp, acid would most likely not be the primary cause of deterioration and deacidification would therefore be an inappropriate method of treatment.

Microscopic analysis was used to identify the fibers in the wallpaper samples. Slides of fibers from the sample materials were first prepared using a stereo zoom microscope and scalpel and then analyzed with a polarized light microscope. *The Particle Atlas* by McCrone, Draftz, and Delly was consulted in order to identify the fibers. This source provided photomicrographs of and information about the sort of cotton that was found in paper products, as well as mechanical and chemical wood fibers. The following photomicrographs were taken from *The Particle Atlas*, under slightly crossed polars at 200x*:*

The Particle Atlas Reference Photomicrographs

Removed for copyright purposes

Figure 4-5: Coniferous mechanical wood

Removed for copyright purposes

Figure 4-6: Coniferous chemical wood

Removed for copyright purposes

Figure 4-7: Nonconiferous chemical wood

Removed for copyright purposes

Figure 4-8: Nononiferous mechanical wood

Removed for copyright purposes

Figure 4-9: Cotton

Once wood pulp had been identified in the sample, certain parameters were developed to determine if deacidification products worked and if they caused any damage to the wallpaper. Color and pH were therefore carefully monitored before and after each deacidification treatment.

4.2 Color Monitoring

Deacidification agents can significantly alter the look of paper, either by causing paint or ink on the surface to run, or by lightening or darkening the overall appearance. Any treatment that caused significant appearance distortions would be considered unsuccessful. Color monitoring was therefore conducted in designated areas before and after deacidification treatments using, a CIE L*a*b* colorimeter to detect changes in color. The colorimeter used for these tests, an xrite model SP62, averaged eight sets of L*a*b* values, which were displayed directly on the instrument's screen and recorded in a database.

Because the colorimeter required an average of eight measurements, eight "X" marks were made in pencil on the ground color of each sample. L*a*b* measurements were taken adjacent to these eight markers before and after the sample had been treated with a deacidification agent. Using an "X" to indicate the area to be measured was problematic. There was no consistency in where the measurement was taken in relationship to the "X" as it was difficult to find the exact location of the first reading. In some cases readings were taken directly below the mark, in other cases to the right, etc. On more than one occasion the same X was measured twice, which may also have skewed data. Consistency was necessary and with the Waverly Place wallpaper there were complications because it was embossed, which created small variations in color even within the 6 mm diameter of the colorimeter's target window.

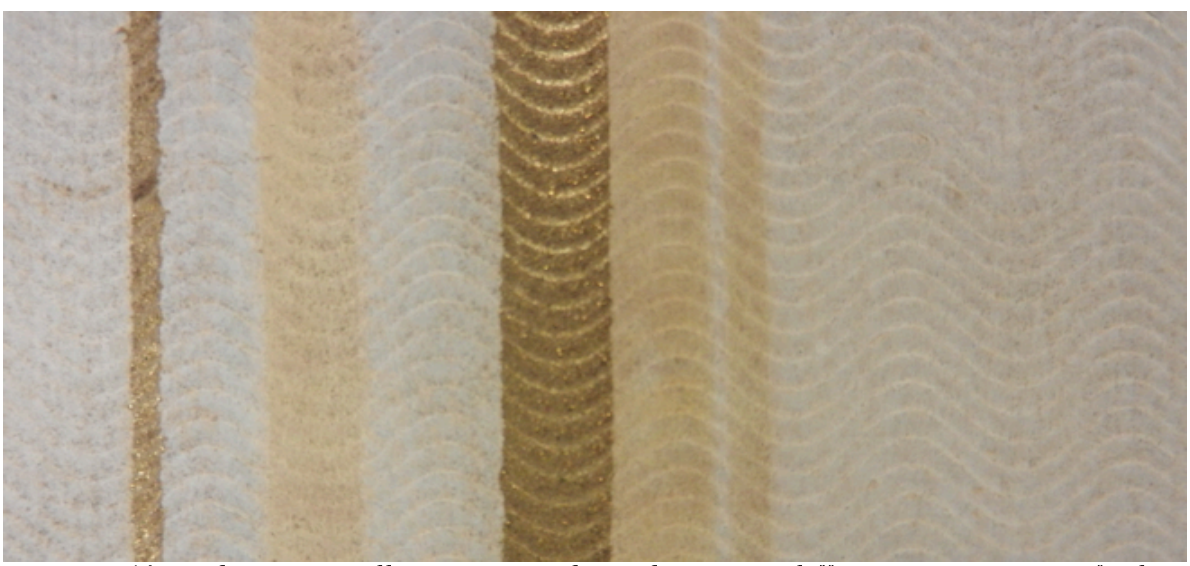
Figure 4-10: Laboratory wallpaper was embossed, creating different appearances of color

In order to increase the accuracy of the colorimeter protocol laid out, eight "X" marks were made on an untreated wallpaper fragment. The same eight points on the ground color were measured twice with the colorimeter and the two averaged sets of data were compared.

Table 4-1: Colorimeter Test: Determining variances in L*a*b* values with one uniform piece of paper

	L*	a*	b*
Reading #1	66.46	+8.66	+21.77
Reading #2	66.77	+8.51	+21.43
Variance	0.31	0.15	0.34

Determining whether the variance values were negligible involved calculating the ΔE value, which is a measurement of the total difference in color.

$\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}$

$\Delta E = \sqrt{(.31^2 + .15^2 + .34^2)}$

$\Delta E = \sqrt{(.0961 + .0225 + .1156)}$

$\Delta E = \sqrt{.2342}$

$\Delta E = .48$

$+ \Delta L$ = Lighter

$- \Delta L$ = Darker

$+ \Delta a$ = Redder

$- \Delta a$ = Greener

$+ \Delta b$ = Yellower

$- \Delta b$ = Bluer

The minimal detectable difference in color to the human eye is approximately 1 ΔE value,[74] therefore the colorimeter and the protocol established for its use were considered to be as accurate as they needed to be. Minor changes were made to the protocol, however, in order to avoid confusion in the future. Rather than using the letter X to mark where L*a*b* measurements should be taken, the areas selected were marked with a number from one to eight, ensuring no single mark was measured more than once. It was also determined that the measurement should always be taken directly to the right of the number.

L*a*b* measurements were only taken on the ground color of the wallpaper because it was originally hypothesized that any visual changes would affect all colors equally. In some instances, colorimeter readings showed very little change in the ground color after deacidification, despite the sample's perceived overall change in appearance. Therefore, when the next set of tests was conducted *in situ*, the pattern, not just the ground color, was measured for changes.

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74 "Understanding Delta-E," http://www.displaycalibrationonline.com/colorscience_delta.asp.

Various surface dry cleaning agents were also tested on the surface in an attempt to establish more consistency to the color readings. Surface soiling can affect values because deacidification sprays can move dirt around. Dry cleaning was chosen in order to avoid compromising the paint layers on the wallpaper, which were easily destroyed when cleaned with water. The object of cleaning the samples was not to restore the wallpaper to its original visual condition, but simply to eliminate any easily removable soil. Surface cleaning did not address staining or any other discoloration. Products tested include: Sanford® Magic Rub in block and pencil form, Staedtler® Mars® Dry Cleaning Pad and Gum Eraser, and Absorene Dirt Eraser. The Staedtler® Mars® Dry Cleaning Pad and the Absorene Dirt Eraser were the two gentlest and quickest at removing a significant amount of surface dirt. Magic rub block and pencil cleaned tougher dirt, but also removed more of the paint than the others. The Staedtler® Mars® Gum Eraser seemed to be the least effective. The Staedtler® Mars® Dry Cleaning Pad was selected for use on laboratory samples and a similar testing process was repeated *in situ* on the case study wallpaper.

Surface cleaning was also investigated because some of the samples appeared lighter in color after being treated than they had before. 2.5x stereo zoom microscopic analysis showed that Bookkeeper left behind a white residue that appeared immediately after drying. Most of the white deposits created a veining pattern within microscopic cracks in the paint; however, a small amount was also deposited on the surface.

Figure 4-11: White haze developed after application of Bookeeper (2.5x)

Figure 4-12: White deposit on the surface after application of Bookkeeper (2.5x)

A Staedtler® Mars® Dry Cleaning Pad was used after Bookkeeper had dried to remove deposits that were left on the surface.

Table 4-2: Changes in L*a*b* values as a result of spraying laboratory samples with Bookkeeper and of cleaning the surface after spraying

	L*	a*	b*
Before treatment	74.23	+5.22	+15.09
After treatment	75.17	+4.45	+12.24
Variance	0.94 (lighter)	-0.77 (greener)	-2.85 (bluer)
ΔE	3.10		
After cleaning	74.81	+4.67	+12.95
Variance	-.036 (darker)	0.22 (redder)	0.71 (yellower)
ΔE	0.83		

The table shows that discoloration due to the application of Bookkeeper was significant enough to be perceived by the human eye. It caused the paper to become lighter, greener, and bluer in appearance. Cleaning the sample after it was treated began to counteract those changes, making it darker, redder, and yellower, however, not enough to be perceived. Whether a treated wallpaper sample should be cleaned of deacidification deposits *in situ* probably needs to be evaluated on a case-by-case basis, depending on the amount of white deposits and the fragility of the wallpaper.

4.3 pH Monitoring

pH of wallpaper samples was monitored before and after deacidification treatment in order to determine the effectiveness of the various deacidification products. Monitoring pH of paper is difficult because it is a system made up of several materials, rather than simply one material. "The term 'pH of paper' is essentially undefinable because the heterogeneous systems of fibers, additives, and adsorbed water do not conform to the basic definition of pH established for aqueous solutions."[75] Monitoring the pH of wallpaper is even more difficult because its painted patterns and environment create additional variables. The wallpaper used to develop the initial testing protocols had the added difficulties of varying in surface appearance and brittleness within the same piece of paper. pH values therefore differed greatly depending on the section of the wallpaper.

There are two principal methods available for determining the acidity of wallpaper, despite the difficulty in establishing a pH value for paper products: surface testing and extraction method. It should also be understood that the pH values these tests produce only reflect the pH of the small area being used for the test and may not represent all of the wallpaper. These methods were developed by TAPPI, a professional organization that was founded in 1915 as the Technical Association of the Pulp and Paper Industry, which publishes standards for that industry.

TAPPI standards include a surface pH test (T 529), a hot extraction test (T 435), and a cold extraction test (T 509). Although surface pH testing is less destructive than extraction testing, it also only provides a value for the surface of the wallpaper, which is painted, and does not take into account the wallpaper system, including the paper itself, its adhesive materials, or other finishes or substrate material found behind the wallpaper. Extraction pH measurements, which are more destructive, provide a more accurate pH value of the entire wallpaper system. Cold extraction is preferred over hot extraction because not only does it require less working time, it is also believed to provide more accurate results.[76]

Figure 4-13: Surface pH testing, which tends to leave a small stain on the surface of the paper, is much less destructive than extraction tests, which completely destroy the sample.

Surface testing was attempted before destructive extraction tests. Although it only measures the pH value of the surface, it is only the surface that is being treated with the deacidifyer. Therefore measuring changes in the pH at the surface may provide valuable information about the effectiveness of the products. TAPPI standard T

75 Browning, *Analysis of Paper,* 170.
76 TAPPI 435.

529 is also slightly destructive because it requires the placement of water on the surface of the wallpaper, which had water-soluble surface components. The T 529 test was attempted using available equipment, a combination glass electrode rather than the surface electrode that the standard specifies. This test did not produce consistent pH measurements and therefore was stopped.

The TAPPI 509 Cold Extraction was tested next. However, it requires that one gram of paper be used in order to perform the test. 1 g of sample wallpaper measured approximately 5 cm^2, which used up the paper being used to develop protocols quickly. As there was a limited amount of wallpaper for testing, tests using standard notebook paper determined that .5 g could provide pH values that are consistent with 1 g.

Table 4-3: Determining whether 0.5 g paper samples provide comparable pH measurements to 1.0 g samples of the same paper

1 g		.5 g	
Sample #	pH	Sample #	pH
1	9.06	1	8.97
2	9.40	2	9.28
3	9.37	3	9.31
Avg.	9.28	Avg.	9.19
Average Deviation = 0.14		Average Deviation = 0.14	

The test was therefore modified to use half the sample size as it was less destructive of a limited resource. Both pH testing methods, however, provide limited test results, which must be taken into account when analyzing results.

One problem with any pH test is that it is limited to a very small area and does not necessarily represent all the wallpaper on any given wall. Surface testing is confined to the size of a drop of water and extraction only gives a pH value for the extracted paper, which did not exceed 3 in^2 when .5 g samples were used. Because the wallpaper used in the laboratory testing exhibited a variety of visual values and brittleness in a very small area, it was difficult to establish a starting pH value before any deacidification solutions were applied. The pH of one 3 in^2 sample was not necessarily the same as the pH of another 3 in^2.

Another potential complication could lie with the pH meter itself, a Denver Instrument Model 225 pH/Ion Meter. As with the colorimeter, the pH meter values also vary, although this could be due to a slightly uneven distribution of pH in the paper, rather than to deficiencies in the meter. For example, the exact same standard notebook paper was weighed and tested under the exact same conditions. Values for 1 g samples ranged from a pH of 9.06 to 9.40 and .5 g samples ranged from 8.97 to 9.31 (see chart above). The average deviations for these measurements were 0.10 for the 1 g. samples and 0.09 for the .5 g samples, which indicated that the variances were note significant at this pH level. It is, however, good scientific practice to gather as much data as possible and average them in order to obtain the most accurate pH measurements. Because of the limited amount of wallpaper for testing, only three .5 g samples were averaged together.

Following the same pH testing protocol, measurements were also taken in order to determine if soiling contributed to the wallpaper's acidity. It is thought that embedded dirt particles in paper can break the fibers apart and produce acidic byproducts.[77] This hypothesis was initially tested on a section of wallpaper that was neither excessively dirty nor brittle. The differences in pH were very slight and insignificant.

Table 4-4: Comparing the pH values of uncleaned wallpaper to wallpaper that was cleaned

Not Cleaned .5 g Sample		Cleaned .5 g Sample	
Sample #	pH	Sample #	pH
1	5.63	1	5.86
2	5.80	2	6.05
3	5.89	3	6.07
Avg.	5.77	Avg.	5.99
Average Deviation = 0.10		Average Deviation = 0.09	

The same test was repeated on a more soiled section of the wallpaper sample, which was not extremely brittle. Once again, the difference was not significant, suggesting that soiling conditions have no correlation with the level of acidity.

Table 4-5: Comparing the pH values of excessively soiled samples to samples that have been cleaned

Not Cleaned .5 g Sample		Cleaned .5 g Sample	
Sample #	pH	Sample #	pH
1	6.07	1	6.02
2	5.88	2	5.88
3	5.55	3	5.77
Avg.	5.83	Avg.	5.89
Average Deviation = 0.19		Average Deviation = 0.09	

Cleaning was also investigated in order to determine if soiling on the surface of the wallpaper had any effect on the deacidification agents' ability to permeate the wallpaper. Bookkeeper was the only product used to perform this test as there was a limited amount of other products available. Further testing needs to be conducted using the other products to verify these results.

Three samples were cleaned prior to being treated with Bookkeeper spray and three samples were not cleaned prior to treatment as controls. The data did not reveal any significant difference between the two variables, although samples that remained soiled before treatment had slightly higher pH values.

77 Ritzenthaler, *Preserving Archives and Manuscripts,* 344.

Table 4-6: Determining whether surface cleaning affects the pH of samples after they are treated

Not Cleaned		Cleaned	
Sample #	pH	Sample #	pH
1	7.73	1	7.76
2	8.00	2	7.41
3	7.82	3	7.86
Avg.	7.85	Avg.	7.68
Average Deviation = 0.10		Average Deviation = 0.18	

Although this test did not produce enough data to verify that surface cleaning is necessary for product penetration, it is necessary for color monitoring because soiling can move around on the surface of the sample when it is sprayed with a deacidifyer affecting L*a*b* data. Visual changes cannot therefore be measured with soil left on the surface before treatment is applied. The surface may also need to be gently cleaned if deacidification products created white deposits on the wallpaper. While dry cleaning products were tested in order to find the most gentle and effective for the wallpaper samples, the risk of damage to paint as a result of surface cleaning must be taken seriously.

4.4 Testing Protocols as Developed in the Laboratory

1. Examine the paper fibers and verify wood fibers are present: Using a stereo zoom microscope, tweezers, and a scalpel, separate individual fibers from the wallpaper sample and place on a slide. Examine slide with a polarized light microscope and identify cotton and wood pulp fibers by consulting the Particle Atlas.
2. Select three areas of wallpaper to be tested and photograph them. (Note: the first time testing is performed, the size of a .5 g sample will need to be established. Carefully remove 1 in^2 of the wallpaper and weigh it. Remove an additional 2mm of wallpaper until the sample measures .5 g and note the size of the sample when it reaches the target mass.) Cut three squares the size of the .5 g sample in a piece of blotting paper and use the blotting paper to protect areas of the wallpaper adjacent to the samples from being treated with deacidification products.
3. Perform colorimeter readings. Mark eight spots on each color of the selected sample areas with a number, one through eight. Take L*a*b* measurements with an xrite model SP62 colorimeter directly to the right of each numbered marker and record data for each color measured.
4. Gently clean the surface of the samples with a Staedtler® Mars® Dry Cleaning Pad. Only dirt particles that can be easily dislodged should be removed from the surface. Tougher dirt should be left in place so as not to risk removing any of the surface finishes. Photograph the sample again once it is sufficiently cleaned.
5. Measure the same eight points for each color with the colorimeter again and record the L*a*b* data.

6. Treat samples with a deacidification product. Aerosol treatments will be sprayed at a perpendicular angle to the surface of the wallpaper at a distance of 6-8 inches until the entire surface of each sample is saturated. This should take approximately three seconds. Liquid treatments will be carefully brushed on to the surface of the wallpaper until it achieves the same level of saturation as the aerosol products. Photograph the sample again once it has completely dried. No product tested takes longer than one minute to fully dry.
7. Measure the same numbered markers on each sample with the colorimeter again and record the data. Calculate variances and ΔE values: before the samples were initially cleaned and after they were cleaned, and before the samples were deacidified and after deacidification treatment.
8. Cut each sample area away from the wallpaper using a scalpel and store samples in a baggie to be transported to the laboratory.
9. Cut away three .5 g pieces of wallpaper that have not been treated with a deacidification product and store in a baggie to bring back to the laboratory in order to establish a starting pH for the wallpaper being tested. This will help determine the effectiveness of the deacidification products.
10. Examine treated samples using a stereo zoom microscope for any white deposits as a result of deacidification. If necessary, clean surface with a Staedtler® Mars® Dry Cleaning Pad and take a new set of L*a*b* measurements with the colorimeter. Record the L*a*b* data. Calculate additional variances and values.
11. Test pH. pH testing should be carried out on untreated samples first in order to determine the pH of the wallpaper before treatment. Tear sample into small fragments 5-10 mm in size. Place the fragments in a 140 mL beaker, add 10 mL of deionized water and stir until the entire sample is wet. Add an additional 25 mL of deionized water, stir again, cover with a watch glass, and let sit for one hour. Measure the pH of the sample for ten minutes using a pH meter with a glass combination electrode. Record pH measurement. Repeat this process for each sample individually.
12. Repeat entire process for each deacidification product.

Note: Testing protocols that have been established in a laboratory will most likely need to be modified when carried out *in situ* in order to address circumstances that may not have been foreseen or planned for.

4.5 Findings

Nanolime did not cause any change to the pH or visual characteristics of the laboratory samples. It did, however, cause severe respiratory discomfort and was not used *in situ* because of the potential danger it could cause to visitors of the Tenement Museum. None of the products tested caused very much change in pH of the laboratory samples, which were nearly neutral to begin with. Bookkeeper was the only product to raise pH, although only very slightly, while samples treated with Wei T'o and PaperSaver actually measured at slightly lower pH values than the untreated samples. Bookkeeper and Wei T'o caused the most significant visual changes, with Bookkeeper turning samples lighter and Wei T'o turning samples darker. PaperSaver, which turned samples slightly lighter, did not cause noticeable color changes. Changes in L*a*b* data indicate that all products made samples greener and bluer to different extents. More detailed information can be found in Appendix A.

5. IN SITU CASE STUDY: THE LOWER EAST SIDE TENEMENT MUSEUM

5.1 History and Interpretation of 97 Orchard Street

The Lower East Side Tenement Museum is located at 97 Orchard Street in New York City. It is a pre-law tenement house that was home to nearly 7,000 working class immigrants between 1863 and 1935.[78] There are twenty apartments on five floors, as was common in 1860s and 70s tenement buildings, each approximately 350 square feet in size.[79] The simple brick Italianate exterior was constructed with common stock elements, such as the windows and cornice.[80] Interior plaster walls were originally finished with inexpensive calcimine paints, followed by oil-based paints. Wallpaper with popular 19th century floral, striped, and scrollwork motifs began to replace paint finishes in the parlor rooms beginning in the late 1880s.[81] In 1895, New York City law required that wallpaper be removed before another layer was hung because it was believed that wallpaper paste attracted vermin.[82] It was a law that was evidently overlooked at 97 Orchard Street, where up to 22 consecutive layers of wallpaper are found in some rooms.

97 Orchard Street was among the first buildings in New York that were constructed specifically as multiple-family tenement houses, as opposed to single-family rowhouses that were converted into tenements. Conditions were therefore better than in rowhouses because the building was meant to accommodate several families, however, they were still far from comfortable.[83] There was very little space, light, or ventilation and no running water until long after it was required by law.[84] Sweatshops also began to operate out of the building by the end of the 19th century.[85]

The four upper floors were abandoned in 1935, while retail spaces continued in operation until the 1980s, when the museum took over the building. It is common practice during times of economic hardship for landlords to close residential spaces and collect rents only from retail spaces on the lower floors. It spares them the resources necessary to comply with residential codes and enough rent can be collected from retail spaces to still make a profit. This is a phenomenon that would repeat itself during New York's economic turmoil in the 1970s. In 1988, when the founders of the museum discovered the building, the upper floors remained untouched, in the conditions they were left in 1935.

Since 1990, the Lower East Side Tenement Museum has used the physical fabric of 97 Orchard Street in order to interpret the urban immigrant experience. Museum founder and social historian Ruth Abram recognized the lack of such representation in American historic house museums: "We have preserved log cabins and farm houses and honored the gentry by preserving their mansions in homage to our rural history. But most Ameri-

78 http://www.tenement.org.
79 Dolkart, *Biography of a Tenement House*, 36.
80 *Ibid*, 27.
81 *Ibid*, 23.
82 *Ibid*, 63.
83 *Ibid*, 24.
84 *Ibid*, 44.
85 *Ibid*, 54.

cans have their roots in urban America and the tenement is the quintessential embodiment of that experience."[86] These various immigrant experiences are represented in two recreated apartments on each floor of the tenement, while the other two have been stabilized in the 1935 conditions they were found.

A significant contributing factor to the building's integrity was its evident stratigraphy: alterations made over the decades based on changing styles, residents, and health codes. According to the architecture firm, Li-Saltzman, which has done extensive work at the Tenement Museum,

> "It was…imperative that a strategy be devised to protect the layers of physical history evident within the building, since one of the aspects that makes this building such a powerful historical statement is the clear evidence of successive residents and alterations, with layers of paint and wallpaper, peeling plaster, bulging walls, abandoned sinks, and other features providing evidence of the lives of the thousands who moved through this structure and similar buildings across the city… The preservation of 97 Orchard Street is predicated on retaining the palpable sense of history contained with its walls, and on providing both the experience of the tenement as people lived there, and as it was found."[87]

The layering of wallpaper in the building is evidence of the changes that were made to it over time and are crucial to its interpretation. Tour guides discuss the wallpaper stratigraphy in passing as they lead visitors through the building and a new monthly program run by the museum discusses the materiality of the building, including the wallpaper, and how and why the building and its elements are preserved the way they are. The Tenement Museum is an institution dedicated to learning, not just about the immigrant experience in the Lower East Side, but also about historic buildings and how they should be preserved. One reason why this institution was selected for the *in situ* case study was because they are open to examining past interventions, such as the one being tested for this thesis, to determine how well they perform over time.

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86 Robert E. Thomasson, "Orchard Street Tenement Project: A Chronicle of Immigrant Life," *New York Times*, December 31, 1990, 26.
87 Dolkart, *Biography of a Tenement House,* 117.

5.2 Selecting Locations for Testing

Figure 5-1: Apartment, south wall, with testing locations for wallpaper type 1-a, wallpaper type 2, and wallpaper type 3-a

Figure 5-2: Apartment 12, north wall, with testing location for wallpaper type 3-b

Figure 5-3: Apartment 12, west wall, with point of egress added by the museum

Figure 5-4: Apartment 12, east wall, with testing location for wallpaper type 1-b

The first site visit to the Lower East Side Tenement Museum was conducted on April 9, 2012. The purpose of this initial visit was to identify testing locations for deacidification products, to assess the materials and conditions of the wallpapers selected for testing, and to take samples for fiber identification. Five locations in the parlor of apartment 12 on the fourth floor and one location in the parlor of apartment 17 on the fifth floor were selected. These locations were chosen according to the amount of wallpaper that was exposed, the condition of the wallpaper, and approximate date in relation to other finishes and layers of wallpaper. An attempt was made to select wallpapers that varied in age, condition, and exposure to direct sunlight in order to determine how the deacidification products perform under a variety of conditions. Layers of wallpaper with a significant amount of exposure were chosen for testing in preference to layers that were only slightly exposed. Although surface pH testing is less destructive than the extraction testing performed in the laboratory, approximately one square foot of each type of wallpaper was altered by testing procedures. Wallpaper layers with less than one square foot of exposure were therefore not considered for testing.

Figure 5-5: Apartment 17, north wall, with testing location for wallpaper type 1-c

Figure 5-6: Apartment 17, south wall

Wallpaper sample locations came from the parlors of two apartments at 97 Orchard Street. Apartment 12 on the fourth floor is located in the rear of the building, facing west toward what would have been the back yard and is now Allen Street. This room now serves as a point of egress for the museum, and an exterior door and staircase have been erected on the west side of the room which was not extant when people lived there. Several layers of wallpaper can be observed in this parlor, as well as the original paint finishes and plaster and lath walls.

Apartment 12 is the starting point for the Tenement Museum's newest tour about the Moore family, Irish immigrants who lived in the building in 1869. It is interesting to note that this room is the first impression that visitors on this tour have of the interior of the building and most are fascinated by the several layers of decaying wallpaper.

Apartment 17 on the fifth floor is located at the front of the building, facing east toward Orchard Street. This apartment is closed to the public and is used by the museum staff as a storage area. Information about the wallpaper in apartment 12 was available in a study conducted by paper conservator Reba Fishman Snyder in 1997; however, the study did not include the wallpaper in apartment 17 because the fifth floor was too unstable to access at the time. As in apartment 12, many different layers of wallpaper are exposed in addition to the plaster and lath. The east wall in apartment 17 is the wall with the windows and is entirely bare lath. The west wall with the interior window is completely obstructed by boxes and furniture. Both the north and south walls have areas with at least ten layers of wallpaper and other areas with only one or two layers applied directly to a plaster or spackle substrate. On the South wall, it is clear that the single layer of wallpaper was applied after the fireplace was filled in. On both walls, only one layer of wallpaper is found on the area below where the chair rail would have been. There is also, however, a large area on the eastern side of the north wall with only one layer of paper from the baseboard to the ceiling. There may have been a built up closet there that was removed prior to the last wallpaper application. The north wall has a single border layer below the chair rail under the surface layer and the south wall has several borders below the chair rail.

Wallpaper type #1 was tested in three locations that were exposed to different conditions. Wallpaper sample 1-a was located on the south wall of the parlor in apartment 12, with several other layers of wallpaper beneath it. Wallpaper sample 1-b was located on the east wall in the same room, below the interior window. This sample was the second of only two layers on the east wall and was exposed to more direct sunlight than sample 1-1. Wallpaper sample 1-c was located on the north wall of the parlor in apartment 17 on the fifth floor. This sample was found above several other layers of wallpaper, but unlike in apartment 12, it was not the final layer. Apartment 17 had one additional wallpaper layer on top of wall this type of wallpaper. Wallpaper type #1 found in apartment 17 was also much darker and had aged differently than the same paper in apartment 12. Initial pH readings determined that wallpaper type #1 was acidic in all three locations it was tested.

Wallpaper type #2 was test in one location on the south wall of the parlor in apartment 12. It was an earlier layer than wallpaper type #1, with several other layers beneath it, however only enough of it was exposed to test one area. Initial pH measurements confirmed that wallpaper type #2 was acidic.

Wallpaper type #3 was tested on the north and south walls of the parlor in apartment 12. Different levels of sunlight exposure have created different levels of deterioration between two samples of the same paper. Initial pH readings confirmed that this type of wallpaper was also acidic.

5.3 Development of In Situ Protocols

1. ***Fiber identification.*** Small samples, no larger than 10 mm in size were taken in order to identify the fibers in the wallpapers selected for testing. Samples were removed with sharp tweezers from each of the sample wallpapers at the edges where delamination had already occurred. Samples were examined with a polarized light microscope to identify the presence of wood and other fibers.
2. ***Selection of test locations (3).*** An attempt was made to select areas that are as inconspicuous as possible. Whether or not the wallpaper will be visually altered as a result of deacidification will be determined as part of the testing protocol, but it will almost certainly be visually altered from pH testing. Surface pH testing requires wetting the surface of the wallpaper, which may cause staining or removal of the paint. The areas being treated will also be visually altered by the pencil marks required to indicate testing and colorimeter locations.
3. ***Initial pH measurement.*** The extraction method used to measure the pH of laboratory samples was deemed too destructive to use for the wallpaper at the Tenement Museum. Surface pH testing was selected because, although it also damages the paper, it was the least destructive method available. Surface testing can be executed by wetting the surface of the wallpaper and either using pH indicator strips or a surface glass electrode as a measuring tool. A portable hand-held pH meter (Extech ExStik pH Meter PH100) with a flat surface glass electrode was selected because it provides a digital numerical readout directly on the instrument's screen, rather than an approximate range that the indicator strips provide.

Figure 5-7: Extech ExStik pH Meter PH 100

As the surface of the wallpaper needs to be dampened to establish a pH measurement, it is a particularly challenging procedure to conduct *in situ*, where the surface is vertical. A method of wetting the wallpaper sufficiently for pH testing while preventing the water from dripping down the wall needed to be devised. A channel was chiseled in one of the erasers that was tested in the laboratory and had been ruled out as a potential surface cleaning product. The chiseled eraser was pressed firmly against the wall underneath the area where the water was applied. Excess water would pool in the channel and be absorbed by the isolated area instead of running down the wall. This method was later modified by the addition of a small sheet of Mylar between the eraser and the wall. By positioning the end of the Mylar sheet away from the wall, excess water was carried away to the floor, rather than the rest of the wall below.

Figure 5-8: Demonstration of how excess water was directed away from the wall during surface pH testing

pH was measured in three different locations of the same wallpaper and the three values were averaged together to establish a starting pH for the entire wallpaper. The three different pH test locations for each paper all share the same substrate material and are located in the same approximate area, and were therefore considered adequately representative. The area dampened for testing was approximately 3” x 3” and could be more with other wallpapers, depending on their capillary uptake. Starting pH was therefore limited to three readings in order to minimize destruction.

The eraser and Mylar were pressed firmly against the wallpaper, just below where it was dampened (See image above.) Water was applied to the surface until a dampened area of approximately one inch was created. The Calibrated pH meter was pressed firmly and evenly to the dampened surface and held until it equilibrated. This could take several minutes. pH measurement was recorded.

4. ***Mark testing locations.*** One square inch was cut in the center of a piece of 12”x12” Mylar. This limited the application of each deacidification spray to one inch without affecting adjacent areas. Using the Mylar as a stencil, three one-inch squares were traced in three different locations on the wallpaper with a light line weight drafting pencil, in this case, 3H.

5. ***Photograph*** three testing locations in context.

6. ***Mark colorimeter measurement locations*** inside each of the nine squares. Using the 6 mm hole in the target window of the colorimeter, 8 circles were traced on the ground color of each square testing location.

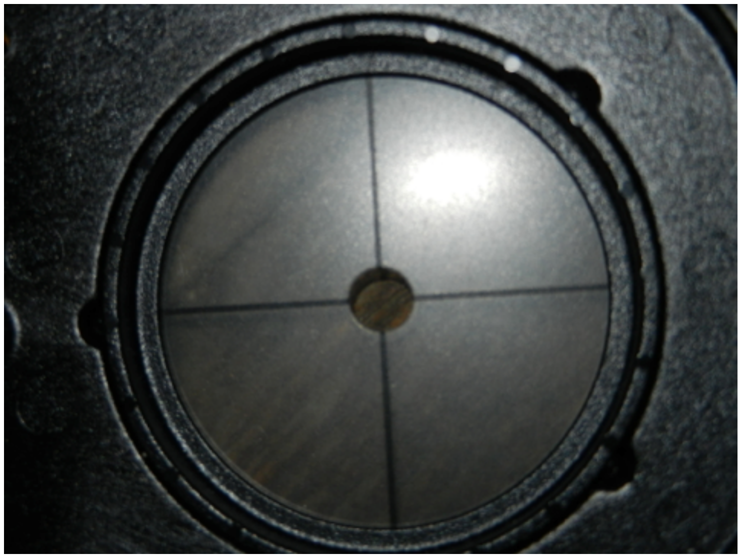

Figure 5-9: Colorimeter target window (6 mm diameter)

The colorimeter requires eight readings to be averaged together to obtain the L*a*b* values of a single color. Using the target window of the colorimeter as a stencil proved cumbersome, however, so a 6 mm circle was cut from a piece of Mylar to use as a stencil instead. In theory, it would be desirable to measure each color of the design because different paints may react differently to the solvents and deacidification agents in the products being tested. The decorative colors, however, are gradient and in many cases not large enough to be measured by the colorimeter, which has an aperture that cannot be adjusted below 4 mm.

Figure 5-10: Wallpaper sample 1-a, Apartment 12, south wall. Printed colors are not wide enough to measure with the colorimeter

The size of the sample area chosen for testing deacidification products was limited to one inch in order to limit the amount of damage. One square inch, however, can only accommodate the eight 6 mm circles required to measure one color. Testing areas would need to be expanded to fit eight circles for each color in the design if they were large enough to measure. Another option was to simply draw 8 circles within a one-inch square, regardless of the color they are drawn on. A mock-up test was run with Bookkeeper on wallpaper #1 in order to determine if it affected different colors differently. Bookkeeper was selected because it most noticeably changed the color of laboratory wallpaper samples.

Colorimeter mock-up test using Bookkeeper

Two squares were drawn about a half-inch apart on wallpaper #1. Eight circles were drawn only on the ground layer in the first square, and eight circles were drawn randomly in the second square, regardless of color. Colorimeter readings were taken in each square. Surfaces were cleaned with the Staedtler pad and another set of colorimeter measurements were taken in each square. Bookkeeper was applied and colorimeter measurements were taken again. Finally, the surfaces were cleaned again and the last colorimeter measurements were taken. ΔE values were calculated to determine if there were any differences in color change between the two squares.

The original intent was to perform this test on the western exterior wall of the fireplace. The copper pipes in the same area prevented colorimeter access and were very hot to touch. The next area chosen for this test was to the left of the radiator. The first problem with this location was that it was too close to the radiator to be able to use the colorimeter. The distance between the edge of the instrument and the center of the target window is about 1 5/8 inch. The first square for testing was placed ½" to 1 ½" away from the radiator, and was therefore too close to be able to access with the colorimeter. This trial-and-error experience should be kept in mind when selecting areas for testing in the future. The second problem was that the line weight of the pencil was too light and could not be seen and in some areas, and also scratched the surface of the paper. A softer 2B drafting pencil was selected as a replacement because it was fine and did not require much pressure. The pencil lines were only very noticeable close up in raking light on such a dark paper.

A new testing location on the same wall, farther away from the radiator was finally selected. This testing location also had to be far enough away from the copper pipes next to the fireplace to not get burned when taking colorimeter measurements.

After the surface was cleaned the first time and the second set of L*a*b* measurements were collected, it was noticed that some circle lines were brighter and easier to detect because paint had been lost only where the pencil marks were. Other pencil marks had been removed from cleaning without taking the paint off, which made finding them more difficult. By the fourth and last colorimeter reading, the circles in the bottom square were all but gone, so measurements were taken using earlier photographs as a guide. It was determined that pencil marks should be made with enough pressure to indent the paper so the circles are not removed by surface cleaning. Indentations in the paper were not considered particularly destructive and if they were not made, colorimeter readings would not be reliable.

Ideally, more than just two squares would be measured and compared but, again, the choice was made to minimize destruction.

Table 5-1: Bookkeeper colorimeter test, Wallpaper type #1 - L*a*b* values before surface cleaning or treating

	L*	a*	b*
Sample #1	37.93	+9.10	+15.22
Sample #2	33.62	+10.10	+12.50

Figure 5-11: Bookkeeper colorimeter test, Wallpaper type #1 - Before surface cleaning or treating

Table 5-2: Bookkeeper colorimeter test, Wallpaper type #1 - L*a*b* values after surface cleaning

	l*	a*	b*	ΔE
Sample #1	40.20	+10.10	+17.32	3.25
Sample #2	36.04	+12.33	+14.38	3.79

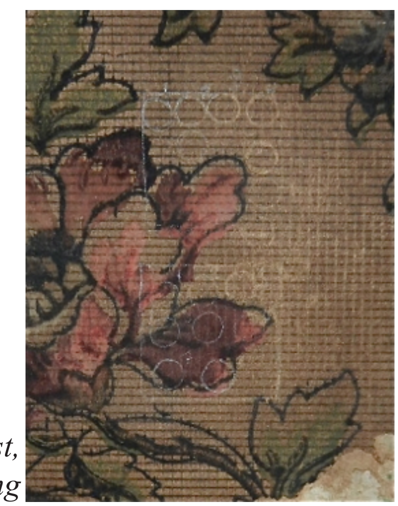

Figure 5-12: Bookkeeper colorimeter test, Wallpaper type #1 - After surface cleaning

Table 5-3: Bookkeeper colorimeter test, Wallpaper type #1 - L*a*b* values after treating

	L*	a*	b*	ΔE
Sample #1	43.70	+8.04	+12.48	6.36
Sample #2	40.49	+10.37	+11.05	5.90

Figure 5-12: Bookkeeper colorimeter test, Wallpaper type #1 - After treating

Table 5-4: Bookkeeper colorimeter test, Wallpaper type #1 - L*a*b* values after surface cleaning after treating

	L*	a*	b*	ΔE
Sample #1	44.67	+8.11	+13.05	1.15
Sample #2	42.09	+9.55	+10.13	2.02

Figure 5-13: Bookkeeper colorimeter test, Wallpaper type #1 - After surface cleaning after treating

ΔE between the final appearance, which is treated and cleaned, and the original appearance of the wallpaper, which is dirty, was 7.15 for the square in which only changes in the ground color were measured and 8.81 in the square in which measurements were taken at random.

ΔE was also calculated between the final appearance and the paper after it was cleaned but before it was treated. This is useful information because the wallpaper's surface would presumably be cleaned before any treatment, so it is in fact this difference in color that matters most. ΔE of the square in which changes in the ground color were measured was 6.49. ΔE of the square in which measurements ere taken at random was 6.85.

These numbers are relatively consistent in this range and it is clear from visual observation that Bookkeeper drastically changed the appearance of wallpaper #1, no matter the color. If they were closer to zero, the differences in ΔE values between the squares before they were cleaned and after they were treated and cleaned (1.66) would be much more significant. It was decided to use these two squares for the Bookkeeper pH testing rather than creating three new squares in another area to limit damage.

Draw eight circles anywhere within the 1-inch squares. This provides more freedom when selecting areas for testing because the amount of each color present in the testing location is not a factor. Press hard enough with the pencil to indent the paper so the marks do not get rubbed or washed away during the testing process.
7. ***Photograph*** area being tested.
8. ***Colorimeter.*** Measure L*a*b* values before anything is done to the wallpaper.
9. ***Clean*** the surface of the sample areas gently with a Staedtler® Mars® Dry Cleaning Pad.
10. ***Photograph*** testing area after it has been cleaned.
11. ***Colorimeter.*** Measure L*a*b* values after cleaning.
12. ***Treat*** three testing squares with a deacidification product. Using the 12” x 12” Mylar shield cut in step 4, spray the product six inches away from the wall until the exposed square is fully saturated. Three squares were clustered in three different areas of the wallpapers and one product was originally tested in each cluster. Begin-

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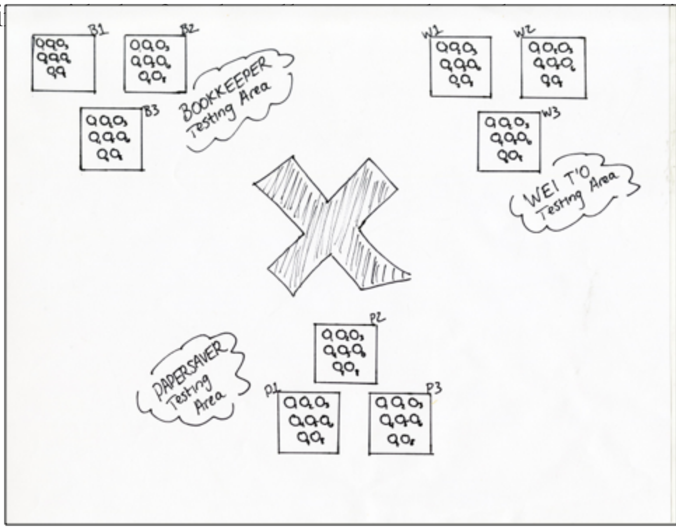


Figure 5-14: Each product was originally sprayed in each cluster

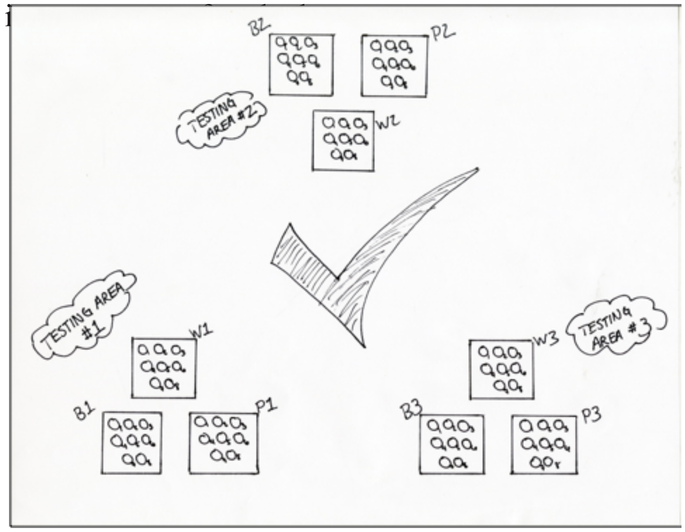


Figure 5-15: Each product was eventually sprayed in one square of each cluster

13. ***Photograph*** the testing squares after they have been sprayed and dried. Drying usually takes several seconds.
14. ***Colorimeter.*** Measure L*a*b* values after treating.
15. ***Clean*** the squares that have been treated.
16. ***Photograph*** the testing squares after they have been cleaned after being treated.
17. ***Colorimeter.*** Measure L*a*b* values after second cleaning.
18. ***Calculate*** changes in color values. Determine the variance in L*a*b* values between each step (8-17) and calculate values
19. Test pH inside the squares, working from bottom to top to avoid wetting other testing areas before they are tested. If possible, try to keep testing areas around chest level. The pH meter may take several minutes to equilibrate and the tester's muscles may begin to shake, in which case the meter moves and cannot take accurate measurements. See step 3 for measuring pH. By the time this pH measurement is taken, the deacidification product will have been left in place for approximately one hour.

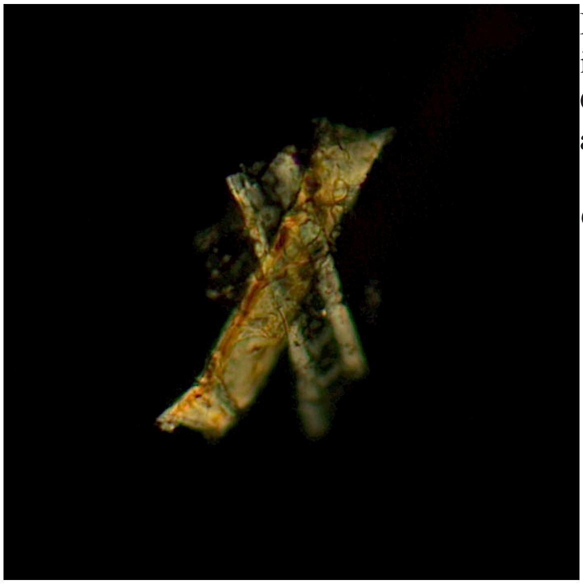
WALLPAPER TYPE #1 - Samples 1-a, 1-b, 1-c

Wallpaper type #1 is a heavily exposed layer of wallpaper in apartment 12 and was the last to be hung in this apartment before it was condemned in 1935 it is also found in the parlor of apartment 17, but it was the second-to-last layer in that apartment. It has a waffle texture that imitates textiles and is printed in a common floral motif with green, pink, and blue colors. Close examination indicates that much of the green shading in the leaves of the design may in fact have been a metallic paint most likely with bronze, which has discolored over time.

Figure 5-16: Wallpaper sample 1-b. Gold colored leaves under the interior window sill have not yet turned green.

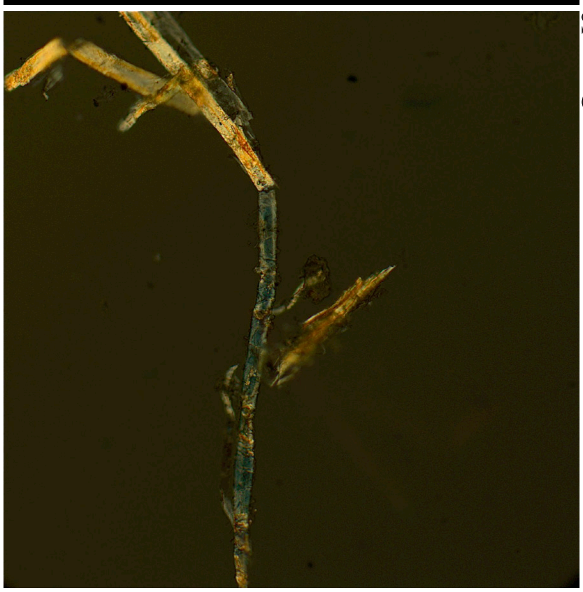
A significant amount of this wallpaper is missing from each of the walls in apartment 12. Although it has become very brown and dark and there are many tears, it appears to be in better condition than the earlier layers beneath it because it is thicker and felt less brittle when removing samples for fiber identification. The tears on the surface also appear to be mainly the result of failure in the substrate layers and do not appear to be due to any inherent flaws in the paper itself. This paper was selected for testing because it was the easiest to access and it is found in different locations throughout the room and in the parlor of apartment 17, with different substrates.

Fiber Identification



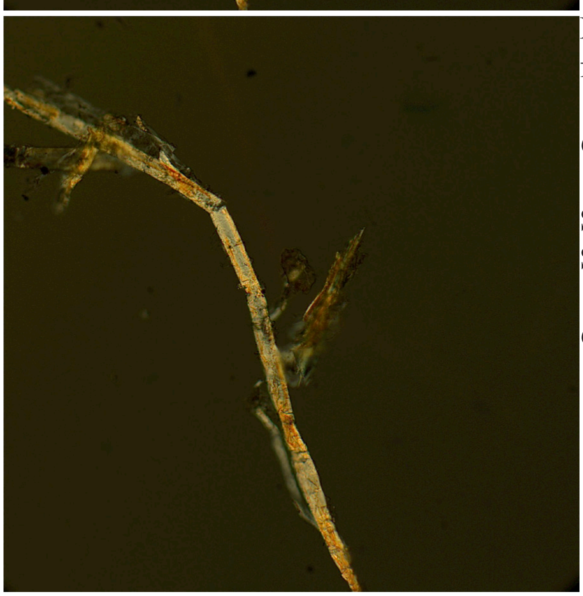
Long, untorn fiber, into the second order of interference, with bright blues and darker reds. Good extinction. Resembles bast fibers like jute and flax.

Coniferous chemical wood



Same as above, rotated.

Coniferous chemical wood



Longer, top fiber: first to second order of interference. Resembles jute and flax.

Coniferous chemical wood

Shorter fiber: first order gray interference. Short, diagonal, brick-shaped cells.

Coniferous chemical wood

Wallpaper sample 1-a is located on the south wall of apartment 12. The testing area for this wallpaper sample is located just above the chair rail, adjacent to the mantle. Because it is located on the south wall, it is exposed to the least amount of direct sunlight, and there are several other layers of wallpaper beneath it.

Wallpaper sample 1-b is located around the interior window on the eastern wall of the parlor, exposing it to more sunlight than sample 1-a. Sample 1-b is only one of two layers of wallpaper over the plaster on the east wall. The areas below and to the right of the interior window were tested.

Wallpaper sample 1-c is located on the north wall of apartment 17 on the fifth floor. At first glance, it does not appear to be the same wallpaper as samples 1-a and 1-b because it has discolored differently. Sample 1-c is not as easily accessible as sample 1-a and 1-b because it is not the last layer in apartment 17. A small area above the chair rail was exposed, which was used for testing.

Figure 5-17: Wallpaper samples 1-a on the left and 1-b on the right. Each has aged differently

Findings

Test result data can be found in Appendix B. Bookkeeper was effective at neutralizing this type of wallpaper but also significantly lightened the color. Sample 1-a averaged a pH of 7.57 after being treated with Bookkeeper but also became significantly lighter in color. It also became greener and bluer. Sample 1-2, which averaged a pH of 6.56 after treatment, also became significantly lighter, as well as slightly greener and bluer. The same visual results were true for sample 1-b, which reached an average pH of 6.81 after being treated with Bookkeeper. After all L*a*b* measurements had been taken, the treated squares were tested for a pH measurement. Dampening the surfaces of the treated squares seemed to eradicate the white discoloration even after the water had dried.

Figure 5-18: Wallpaper sample 1-a the day after the water for pH testing had dried

Wei T'o was only slightly less successful at neutralizing wallpaper type #1 than Bookkeeper and changed its appearance only very slightly. Sample 1-a averaged a pH of 6.26 after being treated with Wei T'o, was neither darker nor lighter than before it was treated, and was only slightly redder and yellower after treating with Wei T'o. Sample 1-b averaged a pH of 5.26 after being treated with Wei T'o. This sample became slightly darker, redder, and bluer than it was before treating. Sample 1-b averaged a pH of 5.98 after treating with Wei T'o. It also became slightly darker and also became slightly greener and bluer. The color changes to sample 1-c were so slight that they were not perceptible to the human eye. Wei T'o was also the only product to bleed outside the square delineated by the Mylar sheet, took the longest to dry, and had the most potent odor.

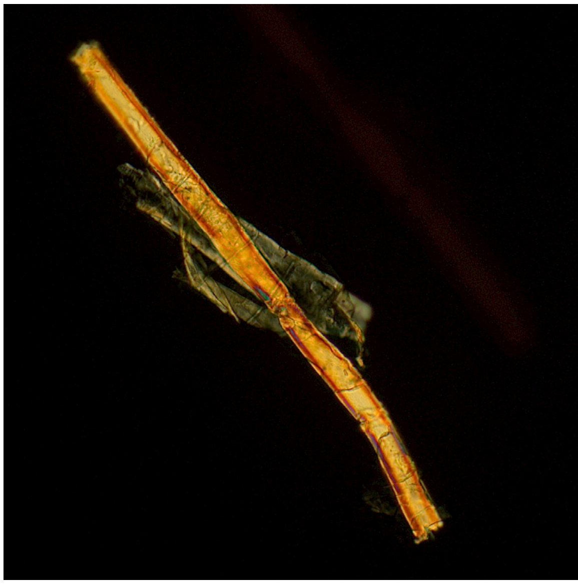
Paper Saver seemed to neutralize some areas very slightly and other areas not at all. It visually turned wallpaper type #1 lighter, especially in the first square that was sprayed. The first square also had a significantly higher pH reading than the other two (6.08 vs. 4.87 and 3.12.) One problem with testing on sample 1-a was that three circles were lost while testing Paper Saver (only one during the testing process). The circles were marked with enough pressure to indent the paper so the pencil marks would not be lost from cleaning or treatment but also with enough pressure to separate the circles from the rest of the wallpaper. This type of wallpaper should be marked with a fine tipped marker rather than a pencil. Loss of material may have skewed colorimeter data, although in this case, the product was not successful and discoloration was visually detectable.

Paper Saver demonstrated similar visual results to Bookkeeper, without its success at neutralizing the paper. Sample 1-a average a pH of 4.66 after treating with Paper Saver and it became much lighter and slightly greener and bluer. Sample 1-b averaged a pH of 4.71 after treating with Paper Saver, however, only a slight color change was measured, although it also became lighter, greener, and bluer. Sample 1-c, which also became slightly lighter, greener, and bluer, averaged a pH of 4.88 after treatment.

WALLPAPER TYPE #2 - Sample 2

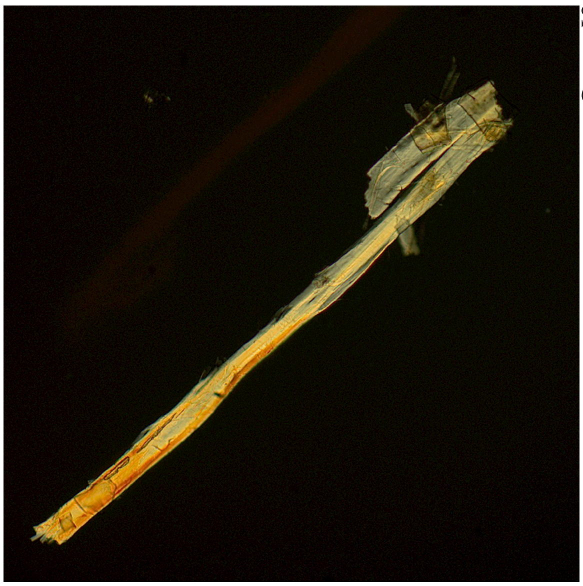
Identified as the eighth layer from the surface by an earlier analysis, Wallpaper type #2 is printed with an abstract floral and scroll design and alternating vertical and horizontal brown and white lines.

The fine green lines in the design, which resemble stencil patterns, may be flocked or faux flocked. This paper is thinner and more brittle than wallpaper #1 and is also more fragmented. Wallpaper type #2 was chosen for testing because it is sufficiently exposed and represents an earlier time period than the first wallpapers, possibly anywhere from sixteen to twenty-four years before wallpaper #1 according to conclusions drawn from the 1997 investigation.



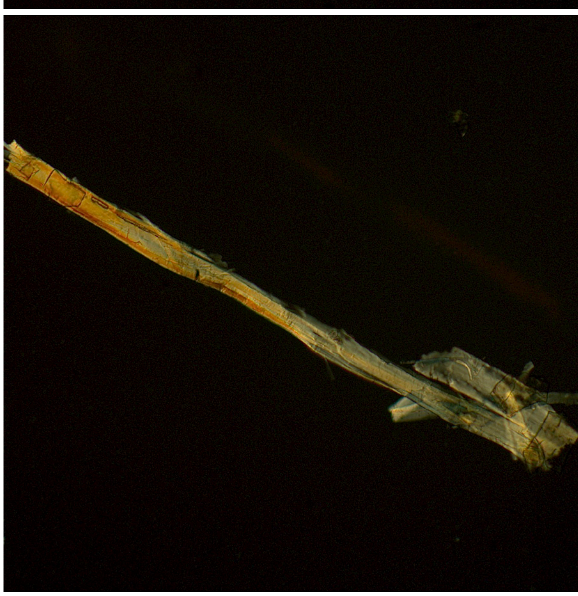
Row of pits in the shorter portion of the fiber. Longitudinal tracheid. First order interference colors.

Coniferous chemical wood



Same as above, rotated.

Coniferous chemical wood



Two rows of pits, first order of interference colors, no mechanical wood properties such as medullary rays.

Coniferous chemical wood

Findings

The testing area for bookkeeper on sample 2 was near the edge of another wallpaper so that it would be less noticeable. However, a nail was located very close to the selected area and in one case too close for the colorimeter to be able to take measurements. The one box that was too close was crossed off and another was drawn just below it. Surfaces should be more thoroughly examined for obstructions such as this before testing boxes are drawn onto the wallpaper.

Bookkeeper neutralized wallpaper type #2 just as effectively as wallpaper type #1 and discolored it to a lesser extent, although discoloration was still visually apparent. (pH 3.86 was raised to 7.43.) As with wallpaper type #1, Bookkeeper caused the wallpaper to turn significantly lighter, and a bit greener and bluer.

Wei T'o successfully neutralized sample 2, raising the average pH from 3.86 to 6.07. Slight darkening of the surface as a result of deacidification was barely noticeable in the first two squares, more so in the third. Wei T'o also caused the wallpaper to become just slightly greener and slightly bluer.

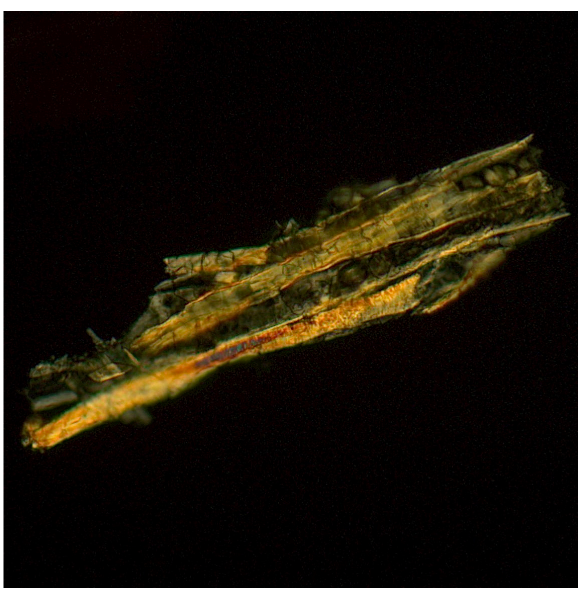
Paper Saver did not visually alter Sample 2, however, it also did not raise the pH. In fact, the average beginning pH was 3.86 and the average pH of areas treated with Paper Saver was 3.52. L*a*b* changes indicate that Paper Saver turned the wallpaper slightly lighter, greener, and bluer, but not to the extent that these changes were perceivable.

WALLPAPER TYPE #3 – Sample 3-a, Sample 3-b

Figure 5-19: Wallpaper *samples 3-a on the left and 3-b on the right. Each has aged differently*

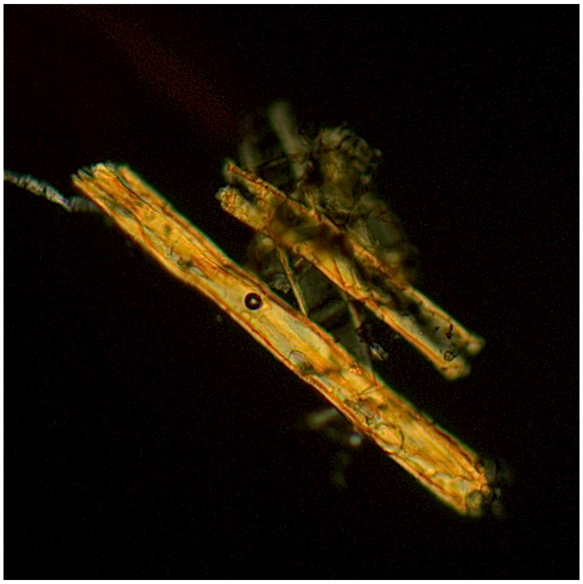
Wallpaper type #3 is the earliest wallpaper in apartment 12, dating probably to the 1880s, and is one of many pink floral and medallion motif wallpapers in this room.

It is several decades older than wallpaper types #1 and #2 and appears to be in the worst condition of the three. It is stained, presumably from water damage in some areas, and bleached in others. The edges are darkened and tearing and the printed design is faded and difficult to read, although a silver glimmer in the vertical stripes is still clearly discernible in raking light. Sample 3-a is located on the south wall of the parlor in apartment 12, while sample 3-b is located on the north wall in the same room. Both samples are adhered directly to a green oil-based paint that is failing and flaking from the surface. Although sample 3-a and 3-b are the same material, they appear different and were found in different conditions because of the differences in their exposure to direct sunlight.



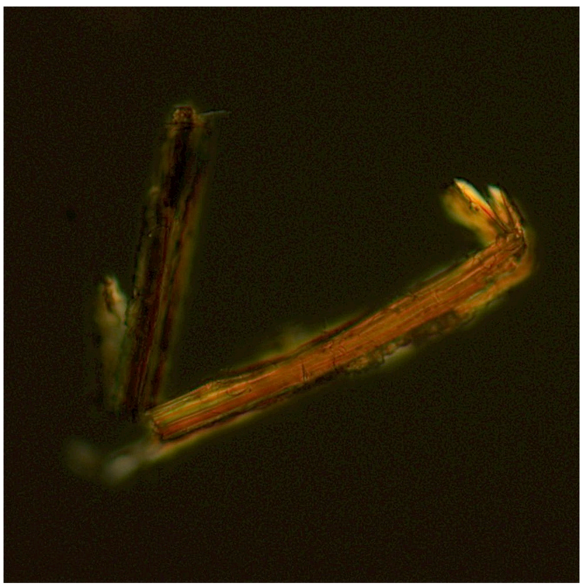
Row of pits, first order of interference colors, no mechanical wood properties such as medullary rays.

Coniferous chemical wood



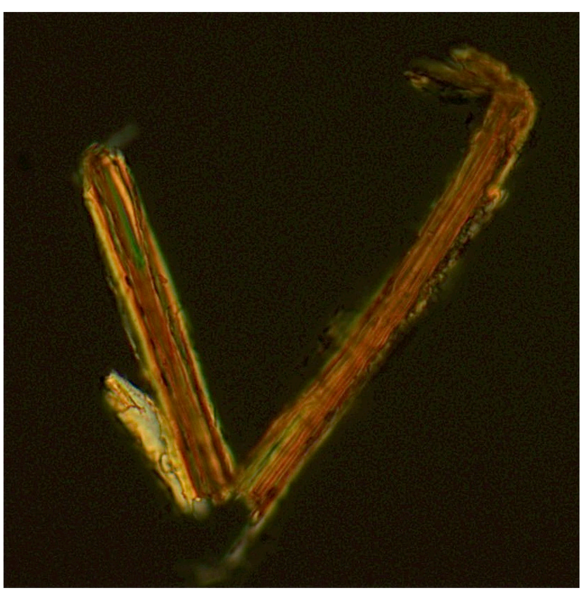
Translucent bundles. Apparent parallel extinction

Bast (Flax or Jute)



Same as above, rotated.

Bast (Flax or Jute)



A row of short brick-shaped cells on a diagonal slant. Interference colors are first order grey with good extinction.

Coniferous chemical wood

Sample 3-a is located on the south wall of apartment 12. The area tested was located directly above the mantle.

Sample 3-b was located on the north wall of apartment 12. Although it differs greatly in appearance from sample 3-a, it is in fact the same paper. Sample 3-b is much more wrinkled and bleached than 3-a, to the extent that the original design is barely discernible. The green-blue oil-based paint layer beneath the wallpaper is also in much worse condition than on the south wall. This sample was chosen because although it is the same paper with the same substrate as sample 3-a, it is evident that its environment, i.e. light exposure, has significantly affected how it has deteriorated.

Findings

Bookkeeper raised the average pH of sample 3-a to a relatively neutral 6.56. There were also significant visual changes, according to the L*a*b* data, which indicated that the sample turned slightly lighter, slightly greener, and much bluer. Visually perceived changes were not as drastic as the data suggests. Sample 3-b reached an average pH of 7.90 after being treated with Bookkeeper and was also made lighter. This sample, however, was made slightly redder, rather than greener and it also became much bluer.

Wei T'o successfully neutralized sample 3-a without noticeably altering its appearance. This is the most successful test so far. Sample 3-a was raised to an average pH of 7.09 without any L*a*b* changes that were drastic enough to be detectable to the human eye. The sample became slightly darker, greener, and bluer. Sample 3-b, which was raised to an average pH of 7.74 after being treated with Wei T'o, was barely visually changed. It became slightly darker, and unnoticeably redder and yellower.

Paper Saver discolored and neutralized the first square it was sprayed on, just as it did on wallpaper type #1. It is not believed that any more product was applied to the first square than the other two. Sample 3-a was barely raised to an average pH of 5.85 and became unnoticeably lighter and greener and slightly noticeably bluer according to L*a*b* data. Sample 3-b was effectively neutralized by Paper Saver. It reached an average pH of 7.06 after treatment. Sample 3-b discolored similarly to sample 3-a, becoming unnoticeably lighter and greener and just noticeably bluer.

CONCLUSION

The goal of this thesis was to determine if vernacular wallpaper could be deacidified *in situ.* Most published wallpaper conservation treatments have discussed expensive wallpapers found in large estates and the homes of historic luminaries. Yet very little has been written about the conservation of mass-produced wallpaper that almost any American could afford.

Deacidification was selected as the method for testing because it would address the most pressing concerns with cheap, wood pulp wallpaper if successful. The best method of preserving paper products is to control their environment. Temperature, relative humidity, exposure to light, and atmospheric pollutants should all be regulated before more invasive and irreversible measures, such as deacidification, are taken. However, controlling the environment of a wallpaper *in situ* is often difficult, and when environmental controls are in place the wallpaper is being preserved for the future and existing damage is not addressed.

When deacidification of wallpaper is performed, it is typically carried out in a laboratory, where both sides of the wallpaper can be cleaned and acids and deterioration products are washed away from the paper in a bath. There are instances, however, when the wallpaper cannot or should not be removed from the wall. In the case of the Tenement Museum, the multiple layers of intact wallpaper are considered a significant part of the architectural integrity of 97 Orchard Street and are crucial to the way the museum interprets the space. Most of these wallpapers are also too brittle to be moved without causing them more damage and their conservation would ideally be conducted *in situ.*

Difficulties Associated With in Situ Testing

As this thesis progressed, it became evident that conserving wallpaper *in situ* poses unique challenges that are not faced in a laboratory setting. Only the surface of the wallpaper can be treated *in situ,* which is not as affective as treating both the front and back. Not being able to remove the wallpaper also precludes the insertion of a lining paper between the wallpaper and the wall, which can significantly prolong the lifespan of the paper. Wallpaper that is treated *in situ* should be regarded as an architectural element, not as an individual artifact, which means it should be considered a part of a greater architectural system. Leaking roofs, cracking walls, and other failures in the architectural system must all be considered in addition to the paper itself and these factors are more difficult to control and account for than simply the wallpaper itself.

Product Test Results

The products tested for this thesis were not ideal. Paper Saver, based upon the testing for this thesis did not produce satisfactory results. With the exception of one instance, it raised the pH of acidic wallpapers only slightly in some cases and not at all in others. It also caused significant discoloration in areas where the pH was raised the most. When Paper Saver was tested in the laboratory several weeks prior to *in situ* testing, it did not cause any noticeable change in appearance. This may be a result of the product reacting differently with a different kind of wallpaper, or there is a possibility that it may have exceeded its shelf life.

Bookkeeper was the most successful product in one respect and the least successful in another. It achieved the highest pH levels *in situ* as well as in the laboratory; however, it also caused the most significant discoloration. Areas of wallpaper that were treated with Bookkeeper were made much lighter. Bookkeeper also tended to make treated areas greener and bluer, with the exception of wallpaper 3-2, which became redder.

Wei T'o was generally successful at neutralizing the wallpaper i*n situ* and also caused minimal discoloration. Unlike the other products, which lightened the paper, Wei T'o caused slight darkening to each wallpaper's appearance. It also raised the pH of all wallpapers tested but not to the extent of Bookkeeper. It is the most successful product because it almost completely neutralized every wallpaper tested, although rarely achieved a pH above 7, while causing little discoloration. Wei T'o is also different from the other products because it was the only one to cause greater values than values, which occurred on wallpapers 1-1 and 1-2.

Recommendations

It is important to note that pH and visual changes to the wallpapers as a result of deacidificaiton occurred on the surface of the wallpaper samples and what happened below the surface was unknown. It is also important to consider what constitutes acceptable visual changes with products that are successful at neutralization. Traditional methods of wallpaper conservation, such as washing the paper in a laboratory, will also cause visual changes. In some cases it may be determined that changes to the look of the wallpaper are worth it being neutralized, and in other cases it may be regarded as detrimental if the visual characteristics of the wallpaper are altered too much.

Base on the limited testing performed for this thesis, Paper Saver was not a successful product for use on the wallpaper at the Tenement Museum. It provided inconsistent results but was for the most part unsuccessful at neutralizing any of the wallpapers and in some cases caused significant discoloration. Bookkeeper was also not a successful product on the wallpaper at the Tenement Museum. Visual discoloration as a result of Bookkeeper, however, makes the wallpaper lighter in color and may not be as noticeable on lighter colored wallpaper. It may be worth a slight visual change given the neutralizing benefits of Bookkeeper. Wei T'o was the most consistent product at raising the pH of the wallpapers tested without causing very much noticeable discoloration and was therefore the most successful product tested. Wei T'o is currently being reformulated by inventor Richard Smith and is expected to perform better on *in situ* wallpaper than the Good News 111 Spray that was tested for this thesis. This product should be tested on wallpaper *in situ* when it becomes available.

Based upon the testing undertaken for this thesis, deacidification is not a treatment that should be taken lightly. None of the three products can be comfortably recommended given the irreversibility of the treatment and the unknown factors involved in deacidification. In recent years, paper conservators have begun to question the role of acidity in the longevity of paper products. It is believed that pH is only one of many factors that affect longevity and that controlling the pH alone cannot be regarded as a "silver bullet" solution for prolonging the lifespan of paper. If pH is the only one of these factors that we can control, does that necessarily mean we should control it? Or should we accept that wood pulp wallpaper has a finite lifespan, and perhaps it is our job as conservators to provide the best possible environment for the wallpaper until its lifespan is complete?

Another factor to consider before using any of these products is scale. Even if Bookkeeper and Wei T'o were used to some success on one square inch of wallpaper, will they be successful on an entire wall? And if so, the toxicity involved at a larger scale should also be considered. The amount of product, and therefore organic solvents, is significantly higher when treating the wallpaper on an entire wall or in an entire room, which can make the process very expensive, and therefore not cost effective for low-budget house museums.

Future Study

Although the products tested for this thesis are not recommended for use on *in situ* wallpaper, it is recommended that the wallpaper that was tested continues to be monitored in order to more fully understand the long-term effects of the tested products. The Tenement Museum may easily locate testing areas in apartments 12 an 17 and continue to test the pH of those areas in the future. It would also be useful for future study to continue to test deacidification products, as they are often reformulated, and to determine how many layers of wallpaper they may penetrate and neutralize. Finally, methods for the preservation of vernacular wallpaper must continue to be investigated in order to protect architectural artifacts that are every bit as relevant as their more expensive counterparts.

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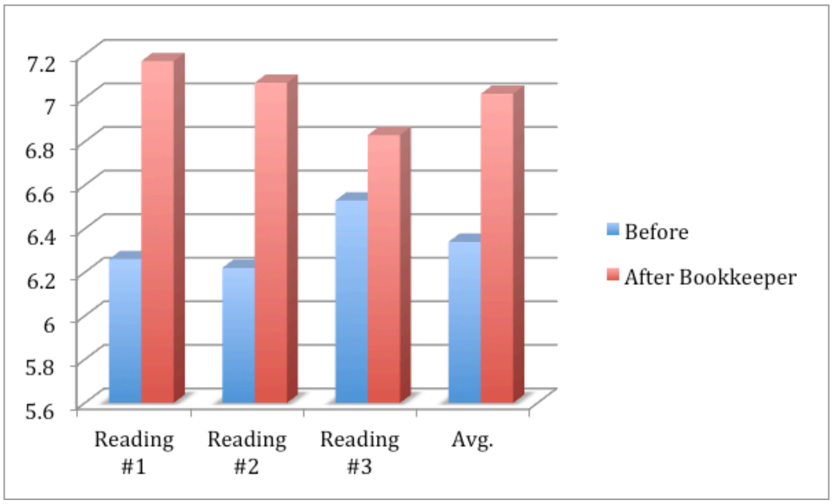
Appendix A - Laboratory Data

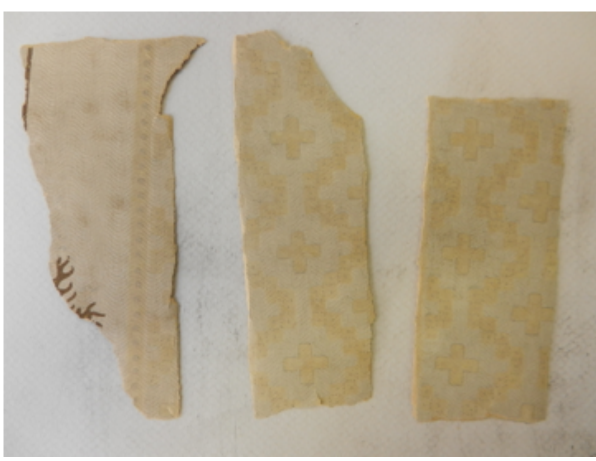
BOOKKEEPER

Change in pH values before and after treating

	Before	**After Bookkeeper**
Reading #1	6.26	7.17
Reading #2	6.22	7.07
Reading #3	6.53	6.83
Avg.	**6.34**	**7.02**



Change in visual characteristics before and after treating



Before Surface Cleaning or Treating

	L*	**a***	**b***
Sample #1	73.70	+5.38	+15.26
Sample #2	72.06	+5.34	+15.33
Sample #3	72.38	+5.01	+14.89
Avg.	72.71	+5.24	+15.16

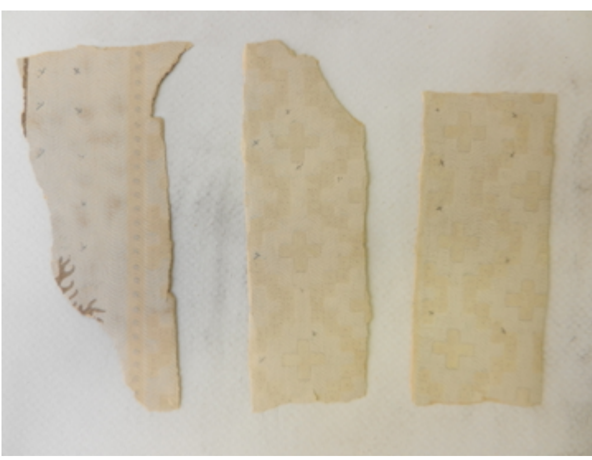
BOOKKEEPER

After Surface Cleaning

	L*	a*	b*
Sample #1	74.89	+5.39	+15.23
Sample #2	73.65	+5.34	+15.33
Sample #3	74.16	+4.93	+14.70
Avg.	74.23	+5.22	+15.09
Variance	1.52 (lighter)	-0.02 (greener)	-0.07 (bluer)
Δ*E* = 1.52			

After Treating

	L*	a*	b*
Sample #1	75.85	+4.44	+11.71
Sample #2	74.71	+4.52	+12.33
Sample #3	74.94	+4.38	+12.67
Avg.	75.17	+4.45	+12.24
Variance	0.94 (lighter)	-0.77 (greener)	-2.85 (bluer)
Δ*E* = 3.10			



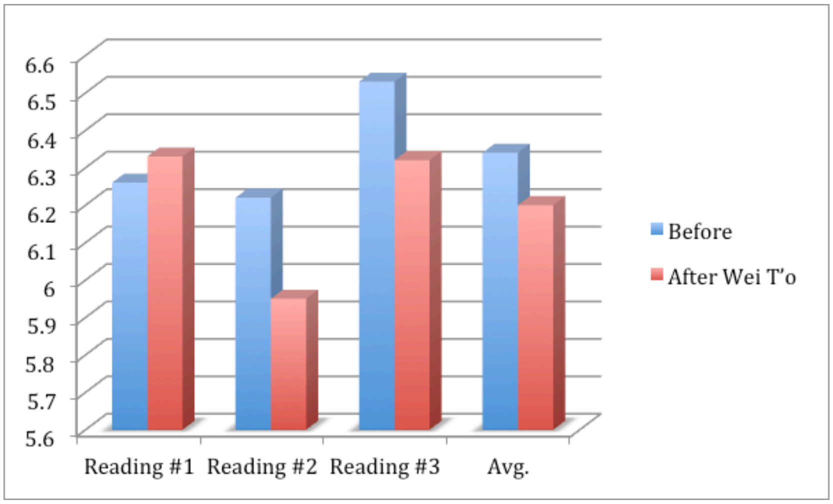
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	75.46	+4.74	+12.69
Sample #2	74.31	+4.76	+13.14
Sample #3	74.65	+4.50	+13.01
Avg.	74.81	+4.67	+12.95
Variance	-0.36 (darker)	0.22 (redder)	0.71 (yellower)
Δ*E* = 0.83			

Variance between L*a*b* values of the sample after it was initially cleaned and after it was treated and cleaned:
ΔL= 0.58 (lighter), Δa= -0.55 (greener), Δb= -2.14 (bluer)
ΔE = 2.28

Change in pH values before and after treating

	Before	After Wei T'o
Reading #1	6.26	6.33
Reading #2	6.22	5.95
Reading #3	6.53	6.32
Avg.	**6.34**	**6.20**



Change in visual characteristics before and after treating

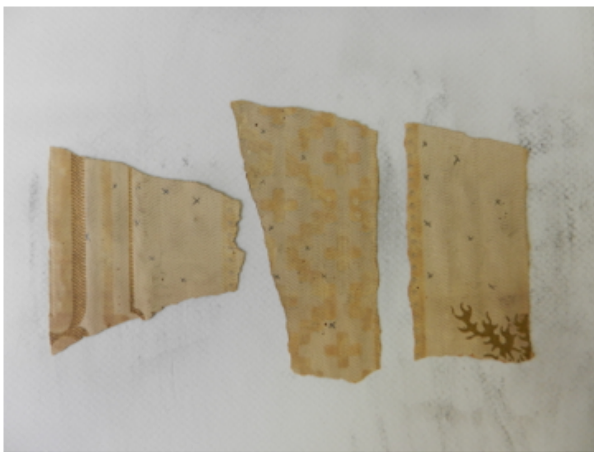
Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	69.43	+7.84	+21.03
Sample #2	66.65	+8.17	+21.38
Sample #3	68.84	+7.78	+20.73
Avg.	68.31	+7.93	+21.05

WEI T'O

After Surface Cleaning

	L*	a*	b*
Sample #1	70.14	+7.71	+20.68
Sample #2	68.06	+8.14	+21.40
Sample #3	69.34	+7.75	+20.67
Avg.	69.18	+7.87	+20.92
Variance	0.87 (lighter)	-0.06 (greener)	0.87 (yellower)
ΔE = 1.23			



After Treating

	L*	a*	b*
Sample #1	68.04	+7.80	+20.90
Sample #2	66.18	+8.24	+21.74
Sample #3	69.34	+7.76	+20.68
Avg.	67.85	+7.93	+21.11
Variance	-1.33 (darker)	0.06 (redder)	0.19 (yellower)
ΔE = 1.34			

After Surface Cleaning After Treating

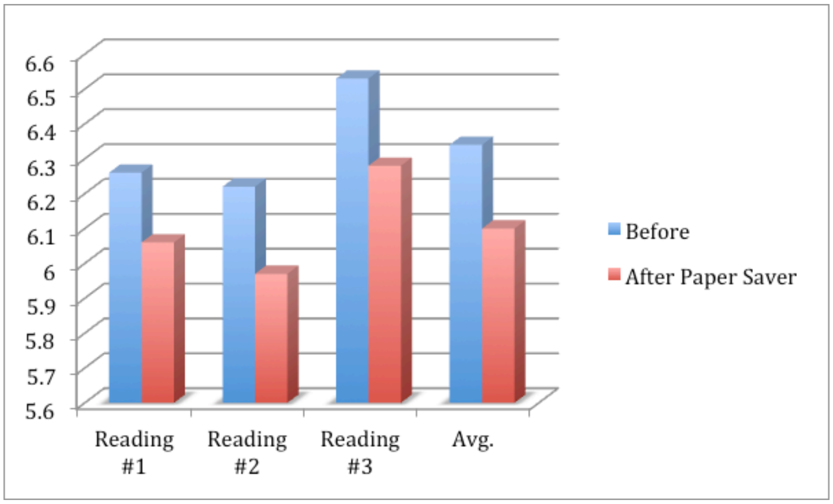
	L*	a*	b*
Sample #1	67.26	+7.61	+20.18
Sample #2	66.05	+8.07	+21.16
Sample #3	67.46	+7.64	+20.28
Avg.	66.92	+7.77	+20.54
Variance	-0.93 (darker)	-0.16 (greener)	-0.57 (bluer)
ΔE = 1.10			

Variance between L*a*b* values of the sample after it was initially cleaned and after it was treated and cleaned:
ΔL= -2.26 (darker), Δa= -0.10 (greener), Δb= -0.38 (bluer)
ΔE = 2.29

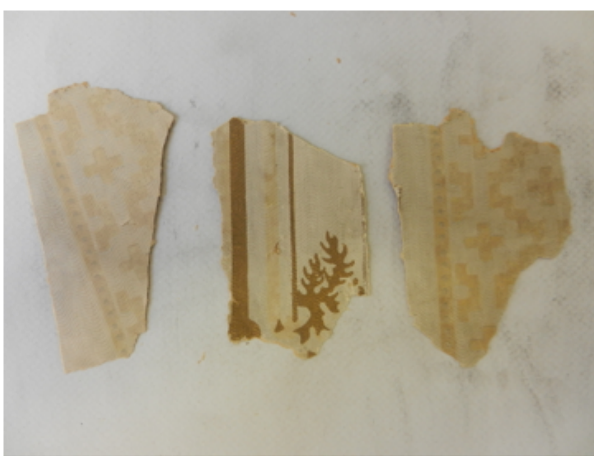
PAPER SAVER

Change in pH values before and after treating

	Before	**After Paper Saver**
Reading #1	6.26	6.06
Reading #2	6.22	5.97
Reading #3	6.53	6.28
Avg.	**6.34**	**6.10**



Change in visual characteristics before and after treating



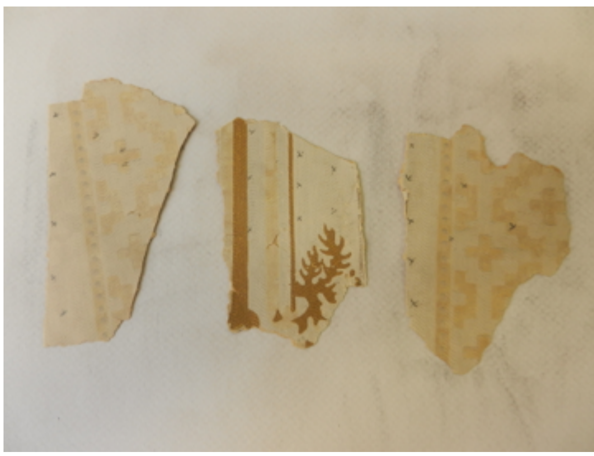
Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	74.23	+5.85	+16.84
Sample #2	73.49	+5.62	+16.05
Sample #3	71.28	+6.48	+18.35
Avg.	73.00	+5.98	+17.08

PAPER SAVER

After Surface Cleaning

	L*	a*	b*
Sample #1	75.53	+5.77	+16.68
Sample #2	75.37	+5.52	+15.86
Sample #3	73.04	+6.41	+18.29
Avg.	74.65	+5.90	+16.94
Variance	1.65	-0.08	-0.14
ΔE = 1.66			



After Treating

	L*	a*	b*
Sample #1	75.72	+5.64	+16.27
Sample #2	75.55	+5.37	+15.41
Sample #3	73.40	+6.12	+17.22
Avg.	74.89	+5.71	+16.30
Variance	0.24	-0.19	-0.64
ΔE = 0.71			

After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	75.46	+5.66	+16.30
Sample #2	75.47	+5.40	+15.48
Sample #3	73.97	+6.21	+17.58
Avg.	74.97	+5.76	+16.45
Variance	0.08	0.05	0.15
ΔE	**0.18**		

Variance between L*a*b* values of the sample after it was initially cleaned and after it was treated and cleaned:
ΔL= 0.32 (lighter), Δa= -0.14 (greener), Δb= -0.49 (bluer)
ΔE = 0.83

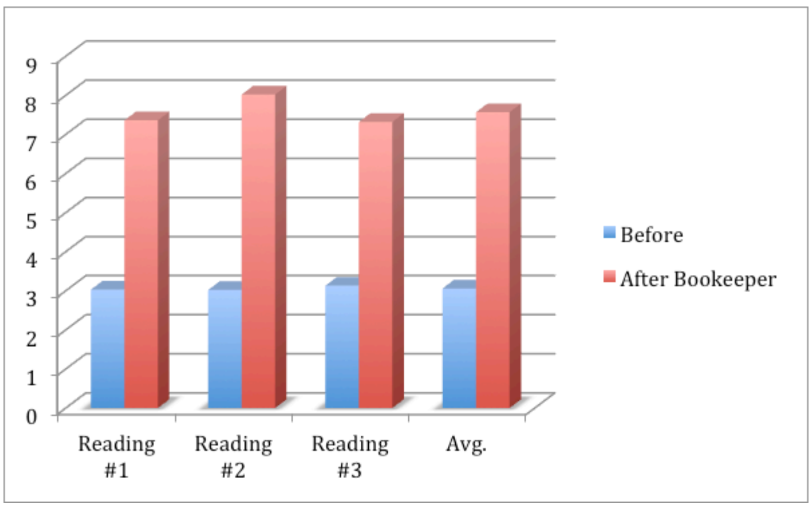
Appendix B - In Situ Data

WALLPAPER 1-a: BOOKKEEPER

*The Bookkeeper testing on wallpaper 1-1 incorporated the two squares created for the establishment of in situ protocols. (See 5.3 – Development of In Situ Protocols, point 6). One additional square was added adjacent to the two squares that already existed from that test.

Change in pH values before and after treating

	Before	**After Bookkeeper**
Reading #1	3.03	7.36
Reading #2	3.02	8.02
Reading #3	3.13	7.32
Avg.	**3.06**	**7.57**



Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	37.93	+9.10	+15.22
Sample #2	33.62	+10.10	+12.50
Sample #3	34.50	+7.50	+10.65
Avg.	35.35	+8.90	+12.79

WALLPAPER 1-a: BOOKKEEPER

After Surface Cleaning

	L*	a*	b*
Sample #1	40.20	+10.10	+17.32
Sample #2	36.04	+12.33	+14.38
Sample #3	35.94	+7.77	+11.27
Avg.	37.39	+10.07	+14.32
Variance	2.04	1.17	1.53
ΔE = 2.81			

After Treating

	L*	a*	b*
Sample #1	43.70	+8.04	+12.48
Sample #2	36.04	+10.37	+11.05
Sample #3	39.40	+7.05	+9.70
Avg.	39.71	+8.49	+11.08
Variance	2.32	-1.58	-3.24
ΔE = 4.29			

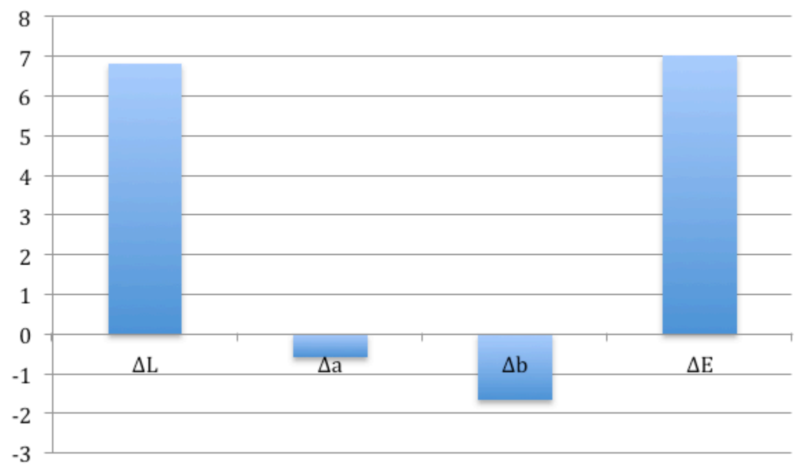
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	44.67	+8.11	+13.05
Sample #2	42.09	+9.55	+10.13
Sample #3	39.69	+7.30	+10.18
Avg.	42.15	+8.32	+11.12
Variance	2.44	-0.17	0.04
ΔE = 2.45			

WALLPAPER 1-a: BOOKKEEPER

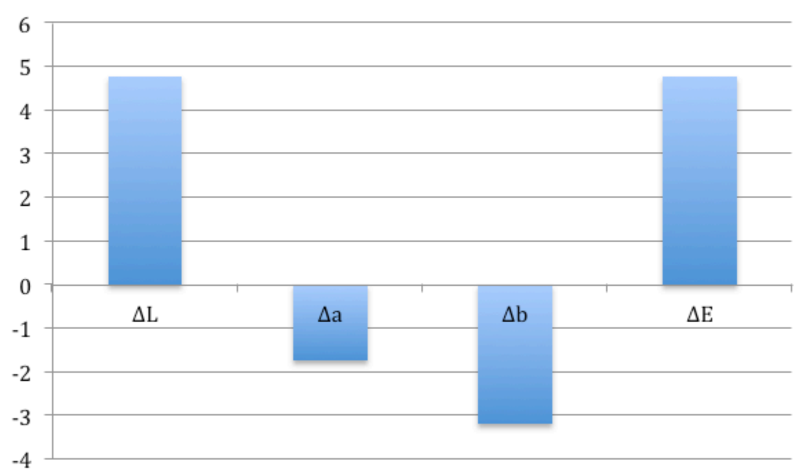
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 6.80 (lighter), Δa= -0.58 (greener), Δb= -1.67 (bluer)
ΔE= 7.03

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 4.76 (lighter), Δa= -1.75 (greener), Δb= -3.20 (bluer)
ΔE = 4.76

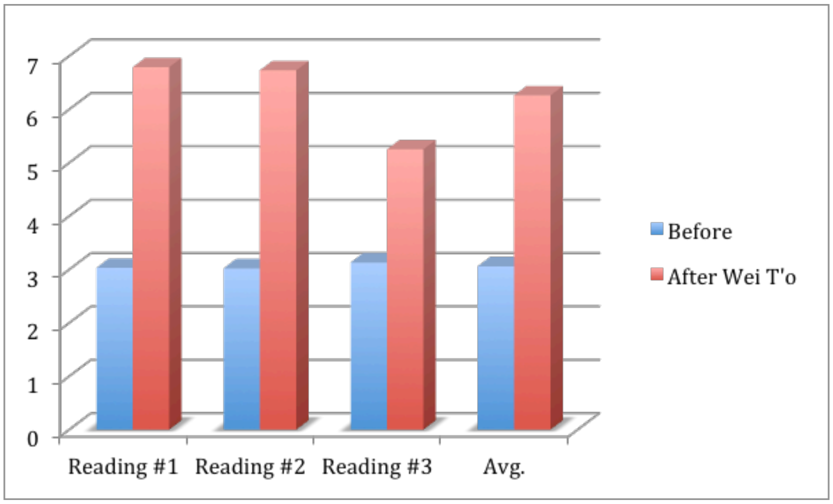
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 1-a: WEI T'O

Change in pH values before and after treating

	Before	After Wei T'o
Reading #1	3.03	6.79
Reading #2	3.02	6.73
Reading #3	3.13	5.25
Avg.	**3.06**	**6.26**



Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	37.23	+8.07	+14.49
Sample #2	36.50	+7.03	+12.45
Sample #3	32.68	+4.97	+10.86
Avg.	35.47	+6.69	+12.60

WALLPAPER 1-a: WEI T'O

After Surface Cleaning

	L*	a*	b*
Sample #1	38.68	+8.25	+15.10
Sample #2	37.88	+7.52	+13.55
Sample #3	34.11	+4.63	+10.19
Avg.	36.89	+6.80	+12.95
Variance	1.42	0.11	0.35
Δ*E* = 1.47			

After Treating

	L*	a*	b*
Sample #1	38.05	+9.06	+17.09
Sample #2	36.17	+7.83	+14.34
Sample #3	34.08	+4.74	+10.52
Avg.	36.10	+7.21	+13.98
Variance	-0.79	0.41	1.03
Δ*E* = 1.36			

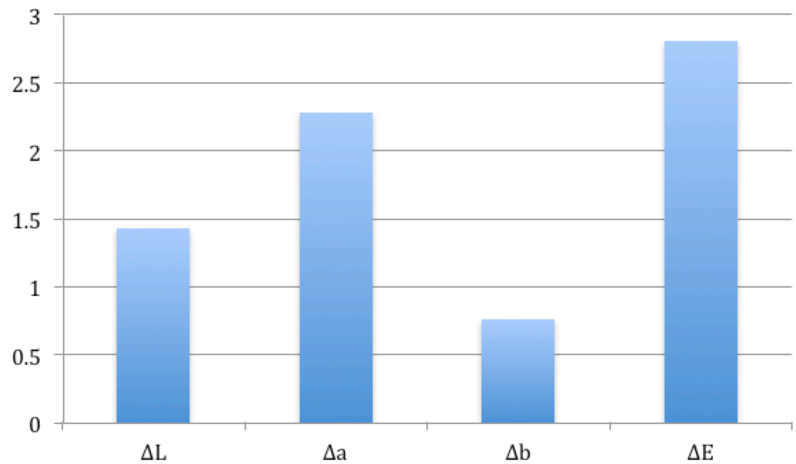
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	38.68	+8.79	+16.49
Sample #2	36.81	+7.46	+13.66
Sample #3	35.22	+13.66	+9.93
Avg.	36.90	+9.97	+13.36
Variance	0.80 (lighter)	2.76 (redder)	-0.62 (bluer)
Δ*E* = 2.94			

WALLPAPER 1-a: WEI T'O

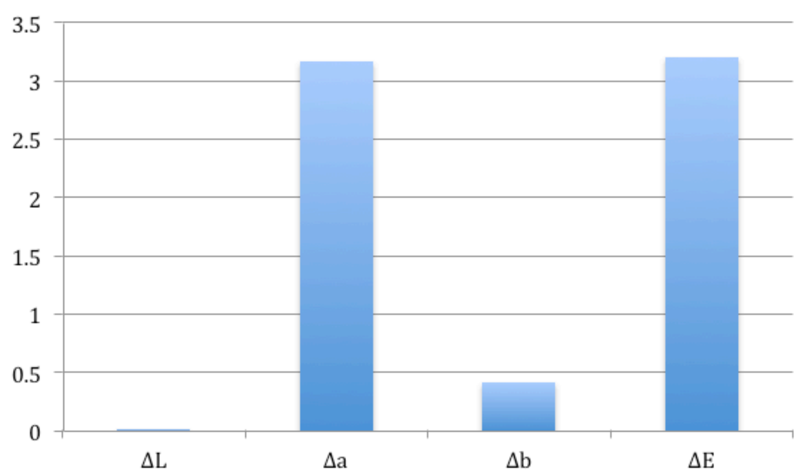
Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 1.43 (lighter), Δa= 2.28 (redder), Δb= 0.76 (yellower)
ΔE = 2.80

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 0.01 (lighter), Δa= 3.17 (redder), Δb= 0.41 (yellower)
ΔE = 3.20

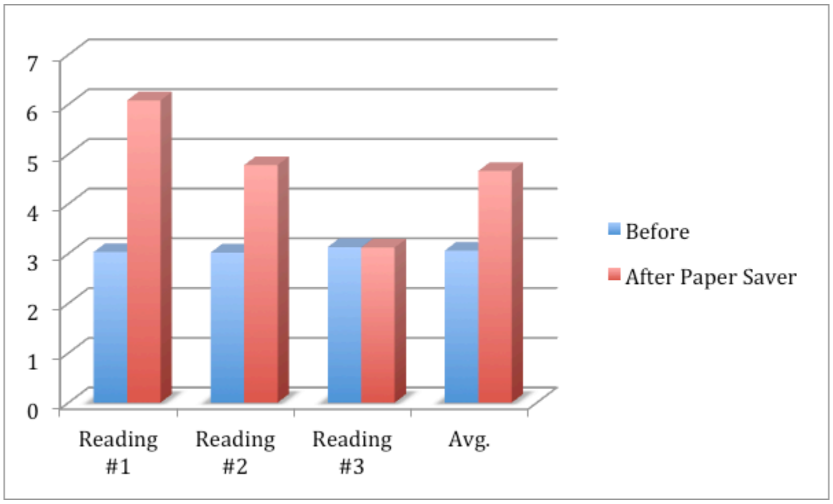
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 1-a: PAPER SAVER

Change in pH values before and after treating

	Before	After Paper Saver
Reading #1	3.03	6.08
Reading #2	3.02	4.78
Reading #3	3.13	3.12
Avg.	**3.06**	**4.66**



Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	36.80	+6.24	+12.02
Sample #2	39.66	+7.26	+13.81
Sample #3	36.98	+6.69	+12.63
Avg.	37.81	+6.73	+12.82

WALLPAPER 1-a: PAPER SAVER

After Surface Cleaning

	L*	a*	b*
Sample #1	38.27	+6.84	+13.20
Sample #2	42.34	+7.78	+15.19
Sample #3	38.17	+6.76	+12.94
Avg.	39.59	+7.13	+13.78
Variance	1.78 (lighter)	0.40 (redder)	0.96 (yellower)
ΔE = 2.06			

After Treating

	L*	a*	b*
Sample #1	48.52	+2.95	+5.00
Sample #2	46.26	+7.55	+15.31
Sample #3	39.06	+6.89	+13.32
Avg.	44.61	+5.80	+11.21
Variance	5.02 (lighter)	-1.33 (greener)	-2.57 (bluer)
ΔE = 5.80			

* Circle #2 in box #2 was lost when sprayed with Paper Saver. Circle number eight was therefore measured twice because both circles 2 and 8 were located on the ground color.

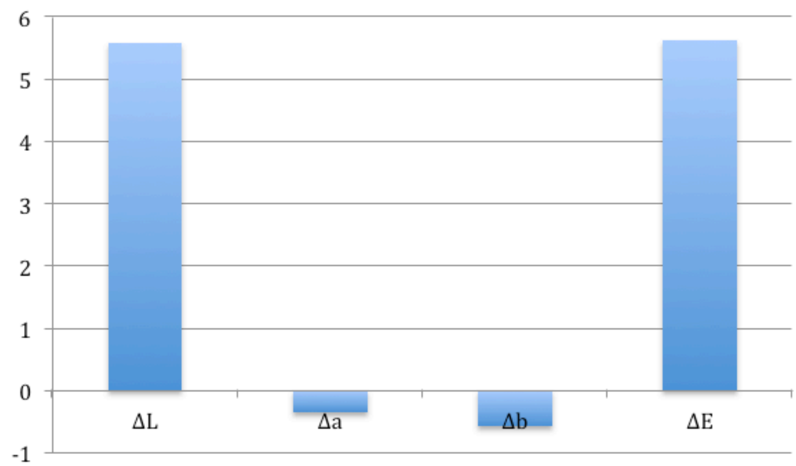
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	43.87	+4.53	+8.43
Sample #2	46.46	+7.75	+15.57
Sample #3	39.82	+6.83	+12.74
Avg.	43.38	+6.37	+12.25
Variance	-1.23 (darker)	-0.57 (greener)	1.04 (yellower)
ΔE = 1.71			

WALLPAPER 1-a: PAPER SAVER

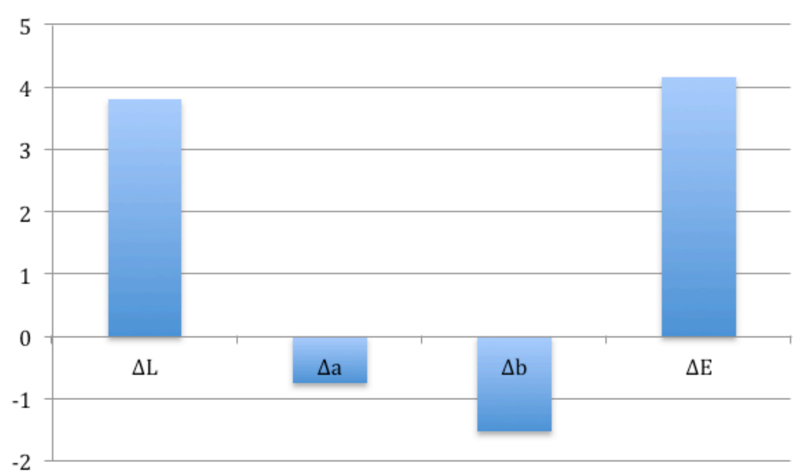
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 5.57 (lighter), Δa= -0.36 (greener), Δb= -0.57 (bluer)
ΔE= 5.61

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 3.79 (lighter), Δa= -0.76 (greener), Δb= -1.53 (bluer)
ΔE = 4.16

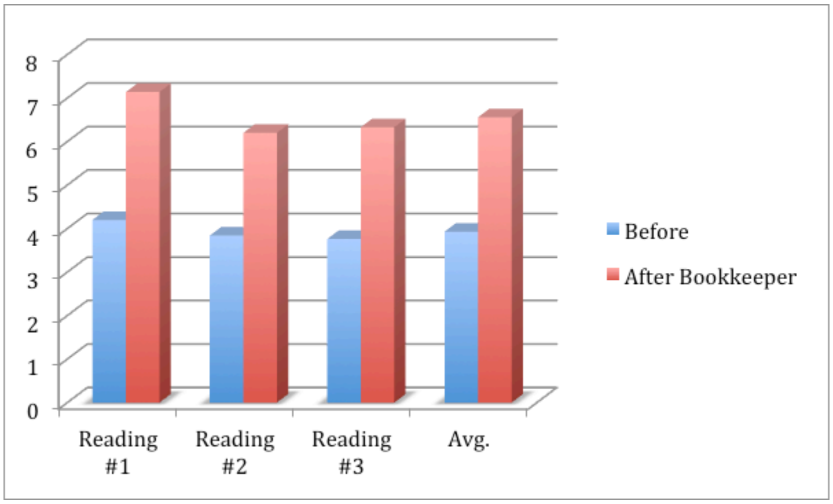
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 1-b: BOOKKEEPER

Change in pH values before and after treating

	Before	**After Bookkeeper**
Reading #1	4.20	7.14
Reading #2	3.84	6.20
Reading #3	3.76	6.33
Avg.	**3.93**	**6.56**



Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	40.96	+11.28	+17.56
Sample #2	40.13	+8.84	+15.58
Sample #3	41.72	+9.36	+14.98
Avg.	40.94	+9.83	+16.04

WALLPAPER 1-b: BOOKKEEPER

	L*	a*	b*
Sample #1	41.39	+11.86	+18.62
Sample #2	40.25	+9.02	+16.00
Sample #3	42.03	+10.79	+17.78
Avg.	41.22	+10.56	+17.47
Variance	0.28	0.73	1.43
Δ*E* = 1.63			

After Surface Cleaning

	L*	a*	b*
Sample #1	43.95	+10.80	+16.49
Sample #2	42.32	+7.91	+13.43
Sample #3	44.31	+8.36	+13.00
Avg.	43.53	+9.02	+14.31
Variance	2.31	-1.54	-3.16
Δ*E* = 4.21			

After Treating

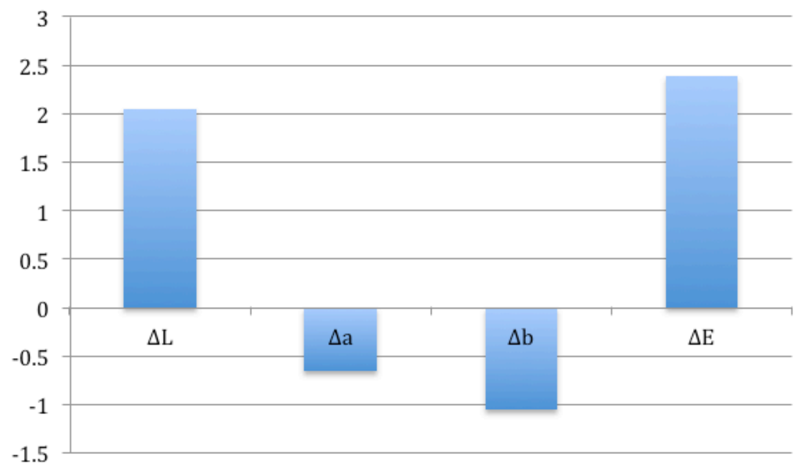
	L*	a*	b*
Sample #1	43.58	+10.53	+16.44
Sample #2	41.88	+7.90	+13.53
Sample #3	43.49	+9.10	+14.96
Avg.	42.98	+9.18	+14.98
Variance	-0.55	0.16	0.67
Δ*E* = 0.88			

After Surface Cleaning After Treating

WALLPAPER 1-b: BOOKKEEPER

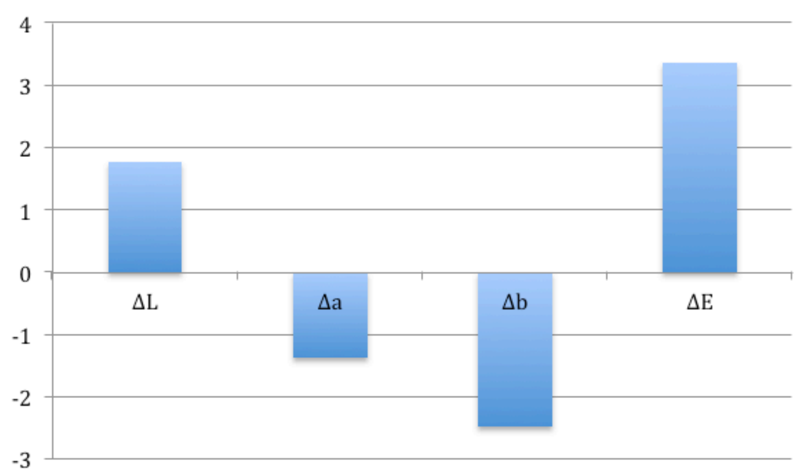
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 2.04 (lighter), Δa= -0.65 (greener), Δb= -1.06 (bluer)
ΔE= 2.39

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 1.76 (lighter), Δa= -1.38 (greener), Δb= -2.49 (bluer)
ΔE = 3.35

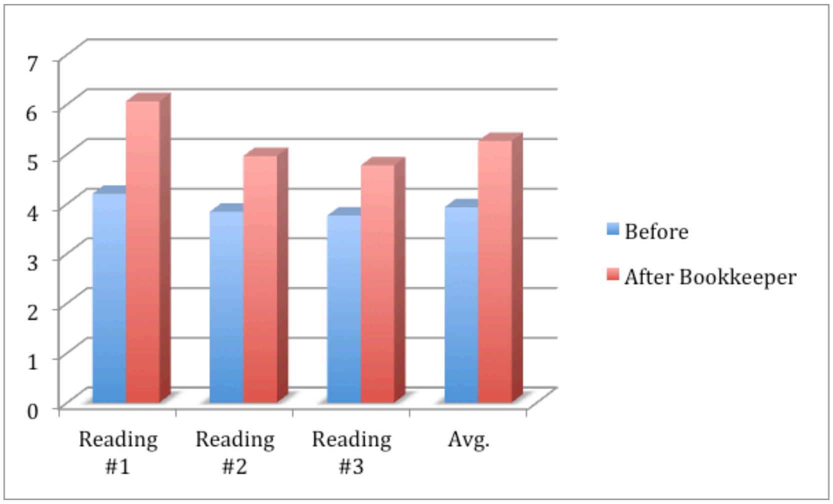
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 1-b: WEI T'O

Change in pH values before and after treating

	Before	After Bookkeeper
Reading #1	4.20	6.06
Reading #2	3.84	4.96
Reading #3	3.76	4.77
Avg.	**3.93**	**5.26**

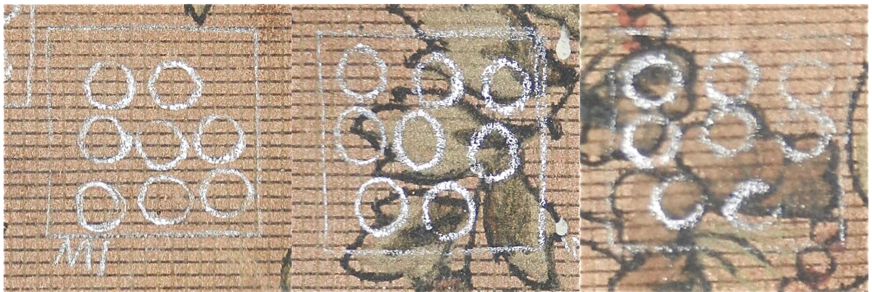


Change in visual characteristics before and after treating

	L*	a*	b*
Sample #1	41.71	+11.10	+18.21
Sample #2	36.25	+6.88	+12.65
Sample #3	37.42	+6.93	+11.35
Avg.	38.46	+8.30	+14.07

Before Surface Cleaning or Treating

WALLPAPER 1-b: WEI T'O



	L*	a*	b*
Sample #1	41.81	+11.33	+18.64
Sample #2	37.11	+6.99	+12.59
Sample #3	37.38	+7.12	+11.51
Avg.	38.77	+8.48	+14.25
Variance	0.31	0.18	0.18
Δ*E* = 0.40			

After Surface Cleaning

	L*	a*	b*
Sample #1	40.65	+12.04	+20.54
Sample #2	36.18	+7.25	+13.54
Sample #3	36.16	+7.22	+11.91
Avg.	37.66	+8.84	+15.33
Variance	-1.11	0.36	1.08
Δ*E* = 1.59			

After Treating

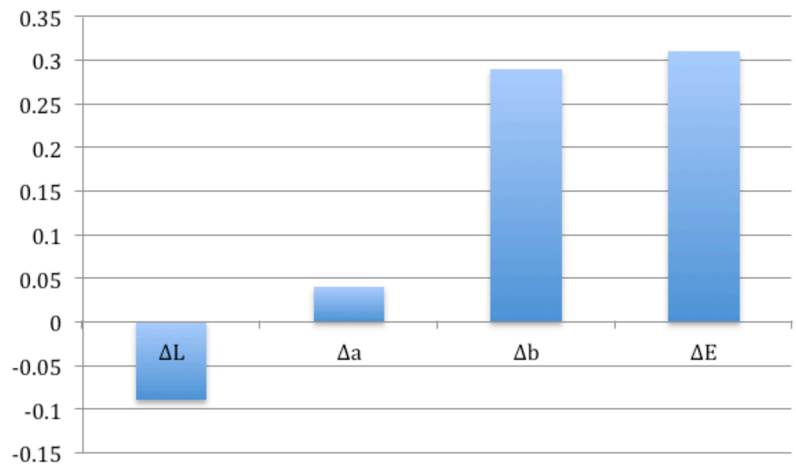
	L*	a*	b*
Sample #1	41.34	+11.41	+19.40
Sample #2	36.79	+6.89	+12.75
Sample #3	36.97	+6.71	+10.94
Avg.	38.37	+8.34	+14.36
Variance	0.71	-0.50	-0.97
Δ*E* = 1.30			

After Surface Cleaning After Treating

WALLPAPER 1-b: WEI T'O

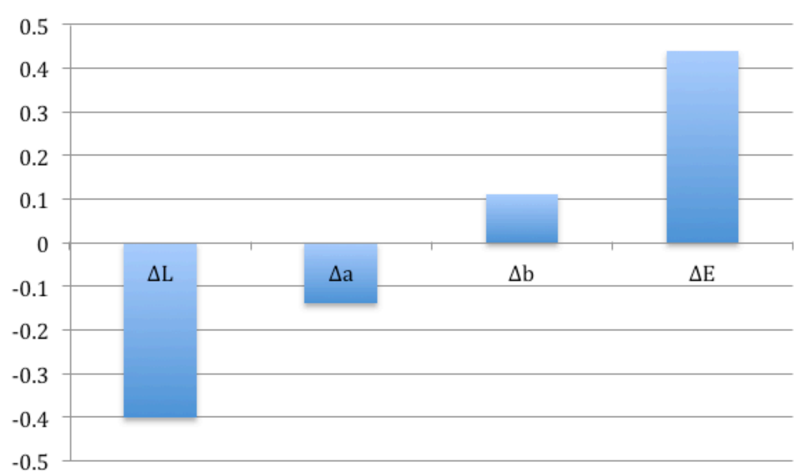
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= -0.09 (darker), Δa= 0.04 (redder), Δb= 0.29 (yellower)
ΔE= 0.31

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= -0.40 (darker), Δa= -0.14 (greener), Δb= 0.11 (yellower)
ΔE = 0.44

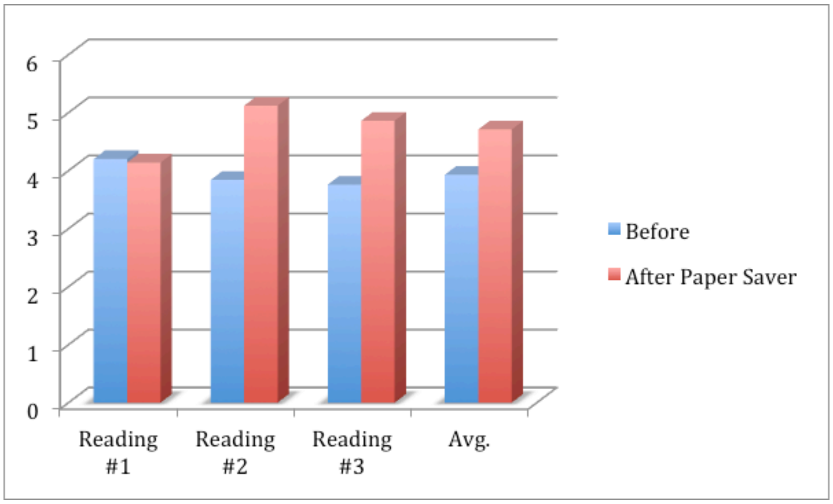
L*a*b* Delta values between second measurements and final measurements



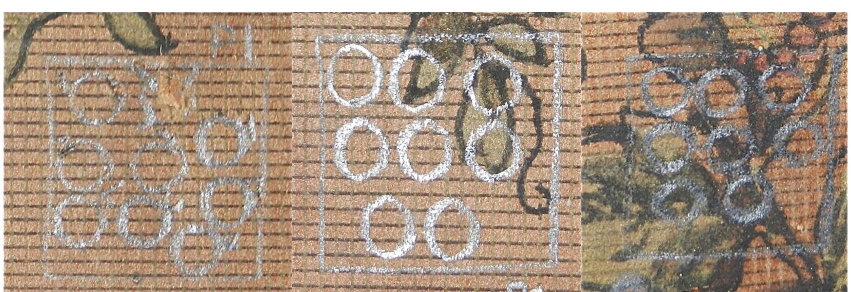
WALLPAPER 1-b: PAPER SAVER

Change in pH values before and after treating

	Before	After Paper Saver
Reading #1	4.20	4.14
Reading #2	3.84	5.12
Reading #3	3.76	4.86
Avg.	**3.93**	**4.71**



Change in visual characteristics before and after treating



	L*	a*	b*
Sample #1	41.30	+10.87	+18.16
Sample #2	40.28	+9.01	+15.52
Sample #3	35.46	+6.25	+10.11
Avg.	39.01	+8.71	+14.60

Before Surface Cleaning or Treating

WALLPAPER 1-b: PAPER SAVER

	L*	a*	b*
Sample #1	41.91	+10.87	+18.30
Sample #2	39.99	+9.24	+15.95
Sample #3	35.38	+6.32	+10.17
Avg.	39.10	+8.81	+14.81
Variance	0.09	0.10	0.21
Δ*E* = 0.25			

After Surface Cleaning

	L*	a*	b*
Sample #1	42.16	+11.10	+18.77
Sample #2	40.60	+8.85	+15.03
Sample #3	37.24	+5.56	+8.77
Avg.	40.00	+8.50	+14.19
Variance	0.90	-0.31	-0.62
Δ*E* = 1.14			

After Treating

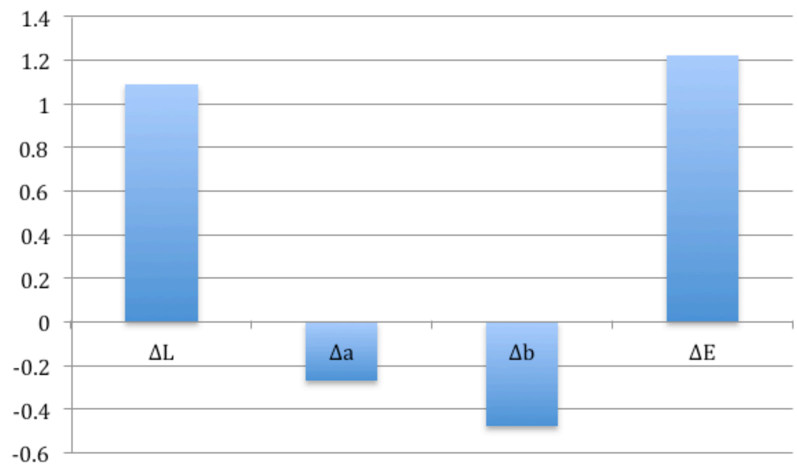
	L*	a*	b*
Sample #1	42.08	+10.97	+18.58
Sample #2	41.37	+8.68	+14.80
Sample #3	36.84	+5.67	+8.97
Avg.	40.10	+8.44	+14.12
Variance	0.10	-0.06	-0.07
Δ*E* = 0.14			

After Surface Cleaning After Treating

WALLPAPER 1-b: PAPER SAVER

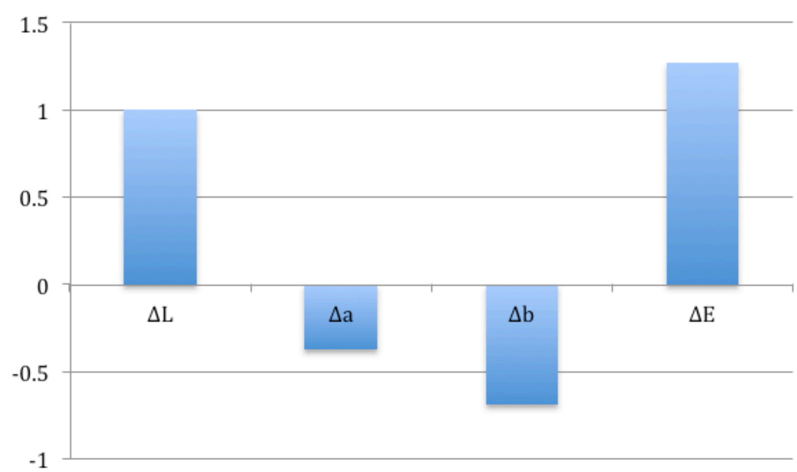
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 1.09 (lighter), Δa= -0.27 (greener), Δb= -0.48 (bluer)
ΔE= 1.22

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 1.00 (lighter), Δa= -0.37 (greener), Δb= -0.69 (bluer)
ΔE = 1.27

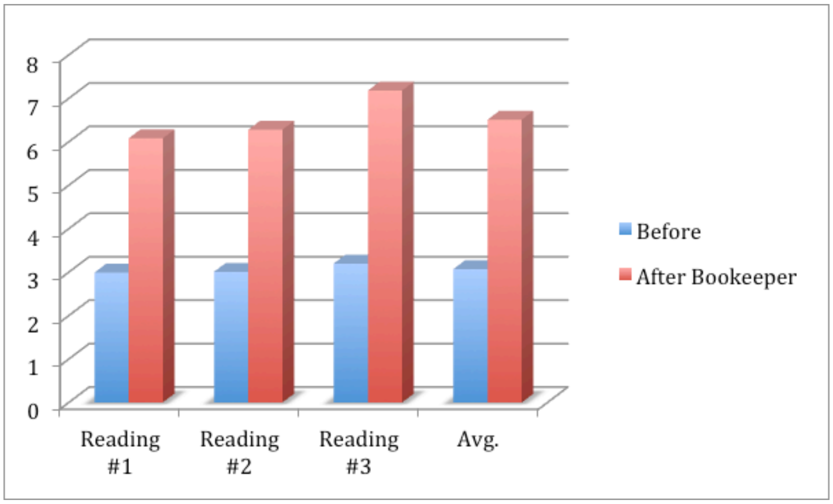
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 1-c: BOOKKEEPER

Change in pH values before and after treating

	Before	**After Bookkeeper**
Reading #1	2.99	6.08
Reading #2	3.01	6.28
Reading #3	3.20	7.18
Avg.	**3.07**	**6.51**



Change in visual characteristics before and after treating

	L*	a*	b*
Sample #1	38.55	+9.24	+15.08
Sample #2	42.25	+9.75	+18.45
Sample #3	46.51	+11.87	+22.82
Avg.	42.44	+10.29	+18.78

Before Surface Cleaning or Treating

WALLPAPER 1-c: BOOKKEEPER

	L*	a*	b*
Sample #1	39.43	+8.50	+13.61
Sample #2	42.80	+9.29	+17.54
Sample #3	46.07	+10.32	+19.54
Avg.	42.77	+9.37	+16.90
Variance	0.33	-0.92	-1.88
ΔE = 2.11			

After Surface Cleaning

	L*	a*	b*
Sample #1	42.70	+7.06	+10.54
Sample #2	45.33	+8.48	+15.66
Sample #3	49.01	+9.41	+17.86
Avg.	45.68	+8.32	+14.69
Variance	2.91	-1.05	-2.21
ΔE = 3.80			

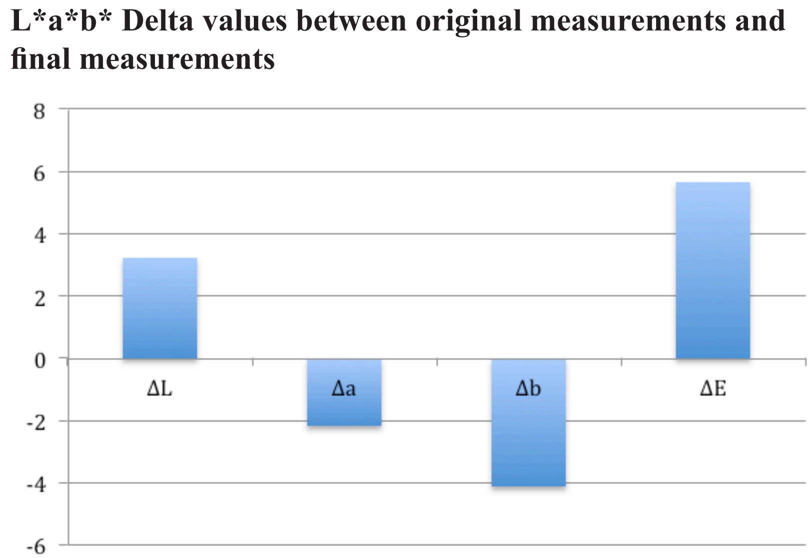
After Treating

	L*	a*	b*
Sample #1	42.58	+6.78	+10.52
Sample #2	45.47	+8.32	+15.57
Sample #3	48.92	+9.27	+17.92
Avg.	45.66	+8.12	+14.67
Variance	-0.02	-0.20	-0.02
ΔE = 0.20			

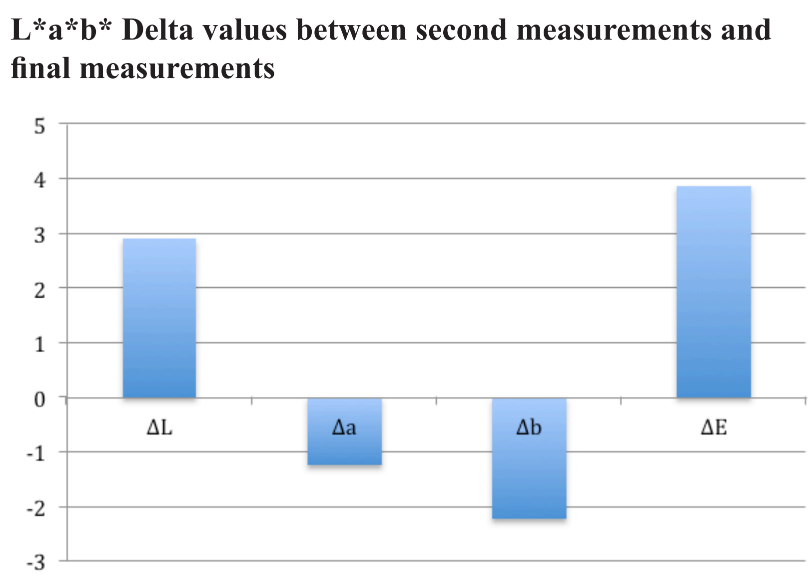
After Surface Cleaning After Treating

WALLPAPER 1-c: BOOKKEEPER

Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 3.22 (lighter), Δa= -2.17 (greener), Δb= -4.11 (bluer)
ΔE= 5.65



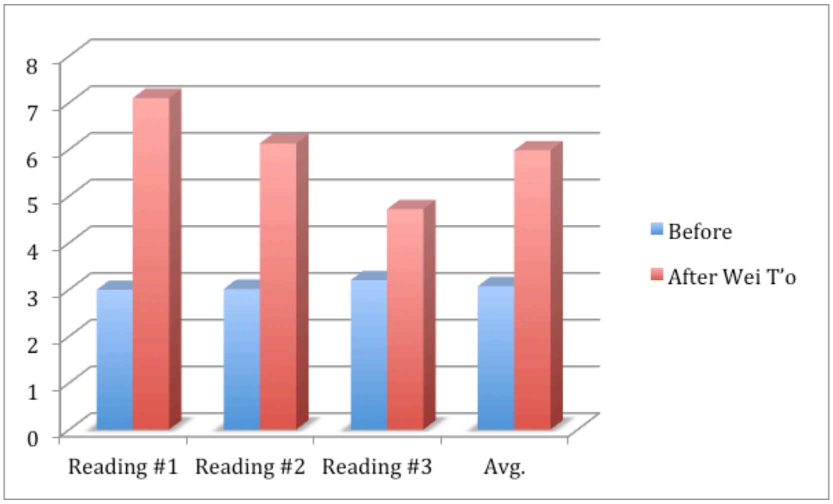
Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 2.89 (lighter), Δa= -1.25 (greener), Δb= -2.23 (bluer)
ΔE = 3.86



WALLPAPER 1-c: WEI T'O

Change in pH values before and after treating

	Before	**After Wei T'o**
Reading #1	2.99	7.10
Reading #2	3.01	6.13
Reading #3	3.20	4.72
Avg.	**3.07**	**5.98**



Change in visual characteristics before and after treating

	L*	a*	b*
Sample #1	45.28	+11.21	+20.94
Sample #2	42.56	+9.53	+17.52
Sample #3	45.04	+11.62	+21.51
Avg.	44.29	+10.79	+19.99

Before Surface Cleaning or Treating

WALLPAPER 1-c: WEI T'O

	L*	a*	b*
Sample #1	45.44	+10.65	+20.01
Sample #2	42.76	+9.13	+16.60
Sample #3	45.76	+10.32	+18.91
Avg.	44.65	+10.03	+18.51
Variance	0.36	-0.76	-1.48
ΔE = 1.70			

After Surface Cleaning

	L*	a*	b*
Sample #1	45.23	+9.98	+18.81
Sample #2	42.02	+9.42	+17.21
Sample #3	43.85	+10.53	+19.74
Avg.	43.70	+9.98	+18.59
Variance	-0.95	-0.05	0.08
ΔE = 0.94			

After Treating

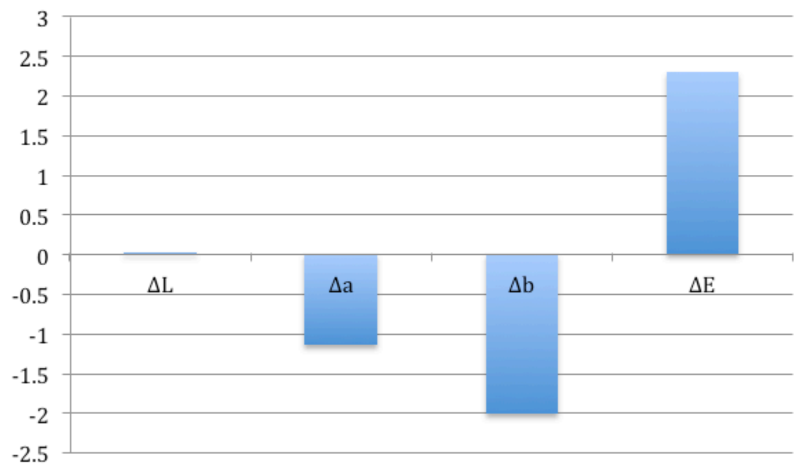
	L*	a*	b*
Sample #1	45.67	+9.93	+18.94
Sample #2	42.89	+9.02	+16.37
Sample #3	44.39	+10.00	+18.67
Avg.	44.32	+9.65	+17.99
Variance	0.62	-0.33	-0.60
ΔE = 0.92			

After Surface Cleaning After Treating

WALLPAPER 1-c: WEI T'O

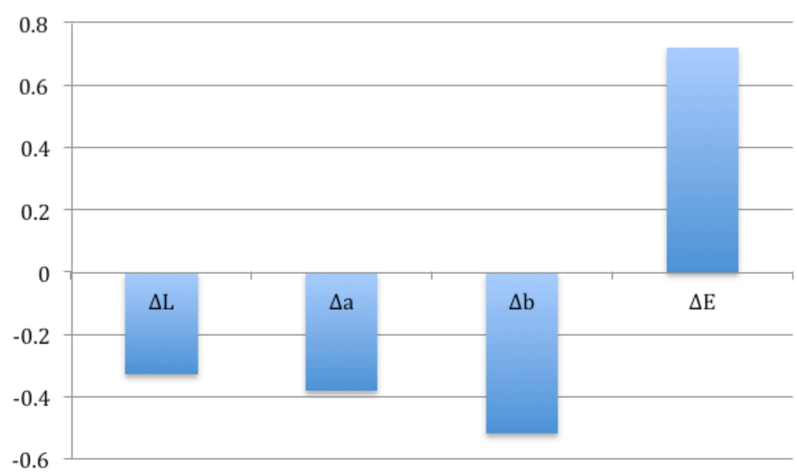
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 0.03 (lighter), Δa= -1.14 (greener), Δb= -2.00 (bluer)
ΔE= 2.30

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= -0.33 (darker), Δa= -0.38 (greener), Δb= -0.52 (bluer)
ΔE = 0.72

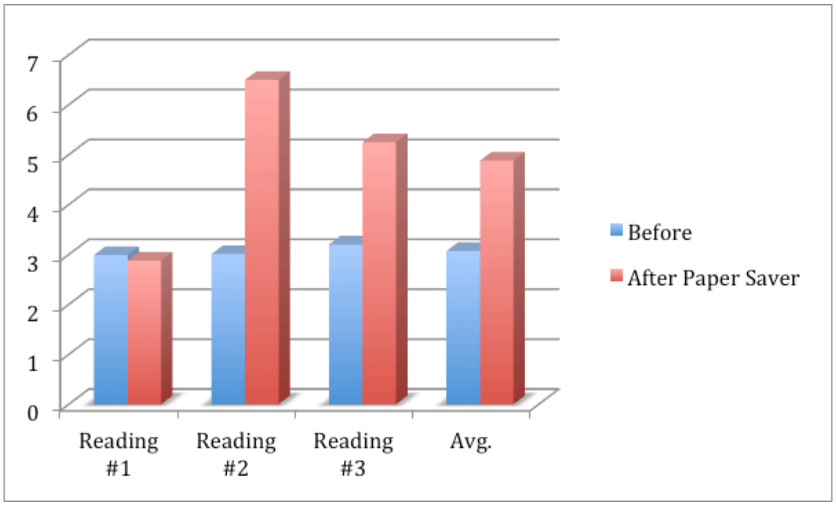
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 1-c: PAPER SAVER

Change in pH values before and after treating

	Before	After Paper Saver
Reading #1	2.99	2.88
Reading #2	3.01	6.50
Reading #3	3.20	5.25
Avg.	**3.07**	**4.88**



Change in visual characteristics before and after treating

	L*	a*	b*
Sample #1	39.21	+8.23	+15.49
Sample #2	42.83	+10.51	+19.15
Sample #3	43.75	+11.49	+20.54
Avg.	41.93	+10.08	+18.39

Before Surface Cleaning or Treating

WALLPAPER 1-c: PAPER SAVER

	L*	a*	b*
Sample #1	39.62	+7.94	+14.91
Sample #2	43.52	+9.92	+18.03
Sample #3	44.49	+10.40	+18.43
Avg.	42.54	+9.42	+17.12
Variance	0.61	-0.66	-1.20
Δ*E* = 1.50			

After Surface Cleaning

	L*	a*	b*
Sample #1	39.27	+7.77	+14.57
Sample #2	46.52	+8.36	+14.80
Sample #3	48.04	+8.88	+15.43
Avg.	44.61	+8.34	+14.93
Variance	2.07	-1.08	-2.19
Δ*E* = 3.20			

After Treating

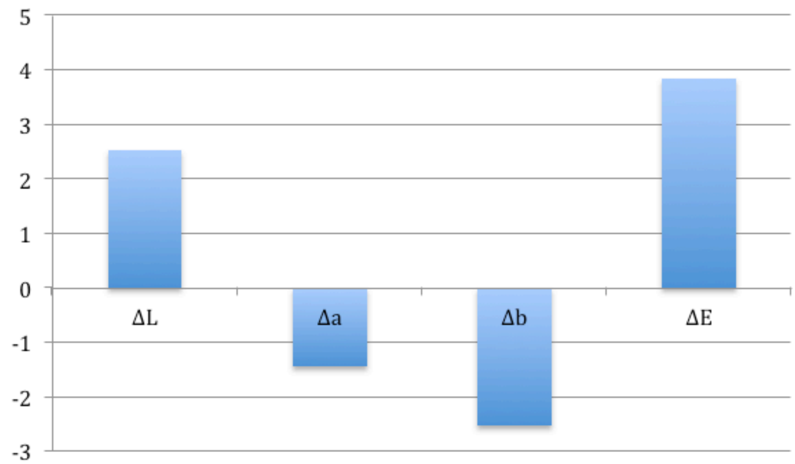
	L*	a*	b*
Sample #1	39.82	+7.77	+14.65
Sample #2	46.44	+8.85	+16.02
Sample #3	47.05	+9.31	+16.90
Avg.	44.44	+8.64	+15.86
Variance	-0.17	0.30	0.93
Δ*E* = 0.99			

After Surface Cleaning After Treating

WALLPAPER 1-c: PAPER SAVER

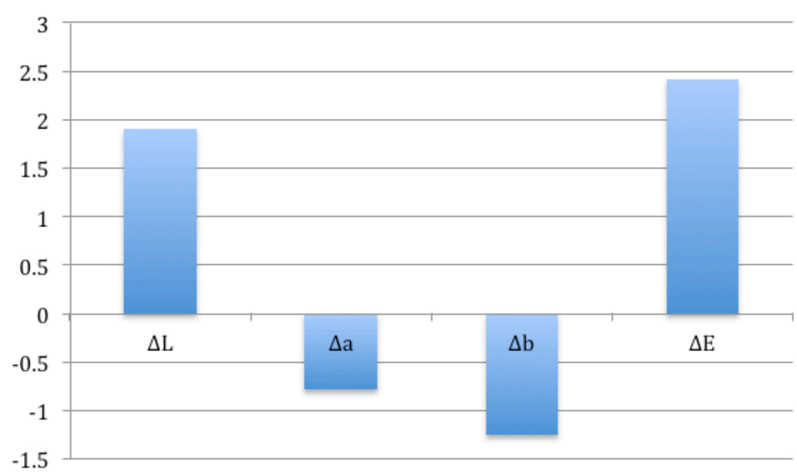
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 2.51 (lighter), Δa= -1.44 (greener), Δb= -2.53 (bluer)
ΔE= 3.84

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 1.90 (lighter), Δa= -0.78 (greener), Δb= -1.26 (bluer)
ΔE = 2.41

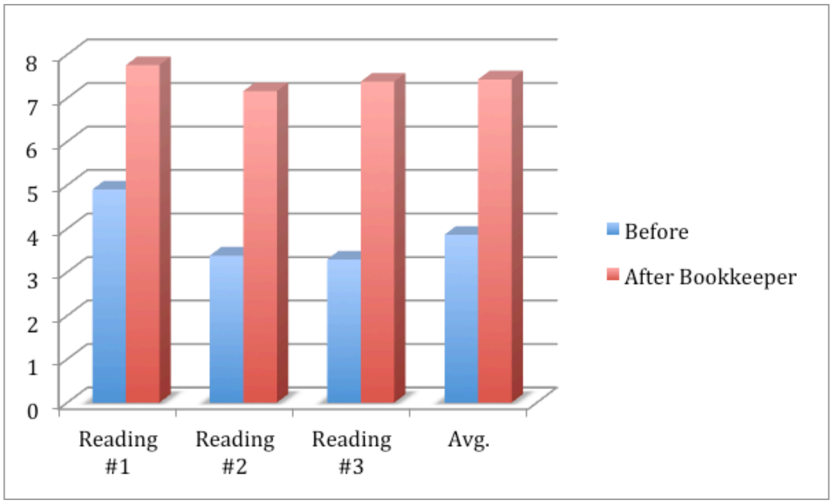
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 2: BOOKKEEPER

Change in pH values before and after treating

	Before	After Bookkeeper
Reading #1	4.90	7.76
Reading #2	3.38	7.16
Reading #3	3.29	7.38
Avg.	**3.86**	**7.43**



Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	46.96	+12.66	+21.97
Sample #2	47.57	+12.31	+21.48
Sample #3	44.70	+11.10	+18.82
Avg.	46.41	+12.02	+20.76

WALLPAPER 2: BOOKKEEPER

After Surface Cleaning

	L*	a*	b*
Sample #1	46.26	+12.45	+21.40
Sample #2	47.05	+12.01	+20.84
Sample #3	44.62	+11.58	+19.57
Avg.	45.98	+12.01	+20.60
Variance	-0.43	-0.01	-0.16
ΔE = 0.46			

After Treating

	L*	a*	b*
Sample #1	49.87	+10.35	+16.60
Sample #2	48.69	+11.13	+18.67
Sample #3	47.04	+10.19	+16.48
Avg.	48.53	+10.56	+17.25
Variance	2.55	-1.45	-3.35
ΔE = 4.45			

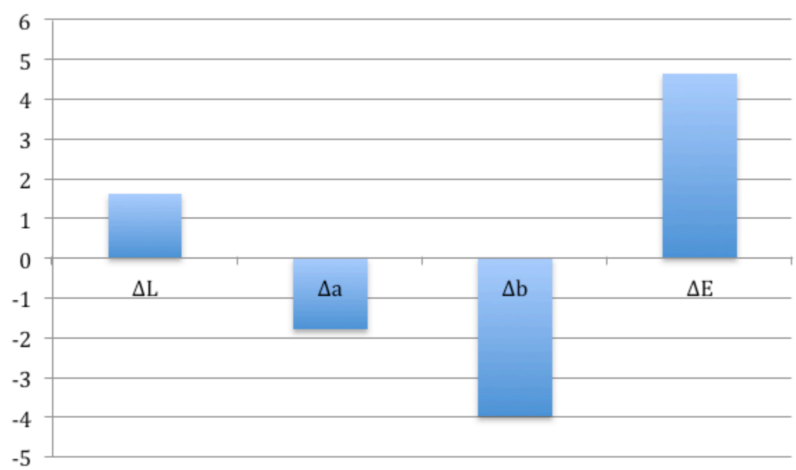
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	49.45	+9.91	+15.98
Sample #2	47.78	+10.66	+17.83
Sample #3	46.82	+10.14	+16.50
Avg.	48.02	+10.24	+16.77
Variance	-0.51	-0.32	-0.48
ΔE = 0.77			

WALLPAPER 2: BOOKKEEPER

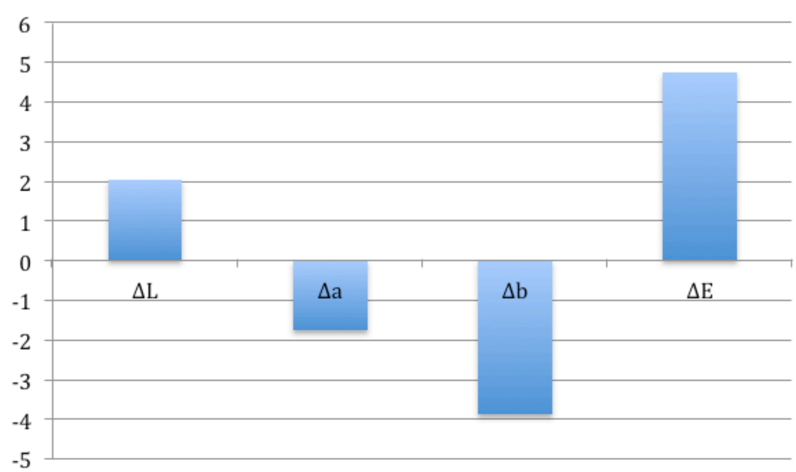
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 1.61 (lighter), Δa= -1.78 (greener), Δb= -3.98 (bluer)
ΔE= 4.65

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 2.04 (lighter), Δa= -1.77 (greener), Δb= -3.89 (bluer)
ΔE = 4.74

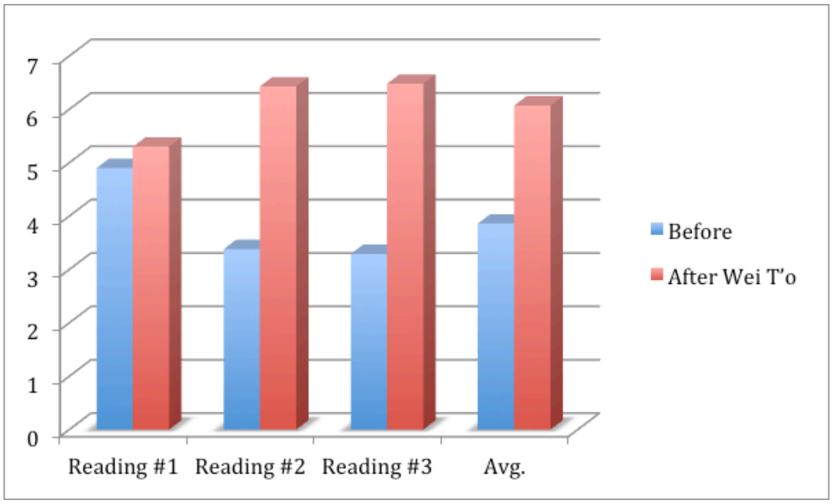
L*a*b* Delta values between second measurements and final measurements



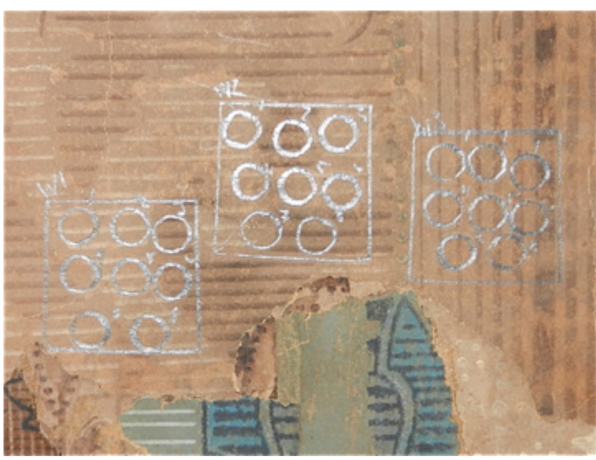
WALLPAPER 2: WEI T'O

Change in pH values before and after treating

	Before	**After Wei T'o**
Reading #1	4.90	5.30
Reading #2	3.38	6.43
Reading #3	3.29	6.48
Avg.	**3.86**	**6.07**



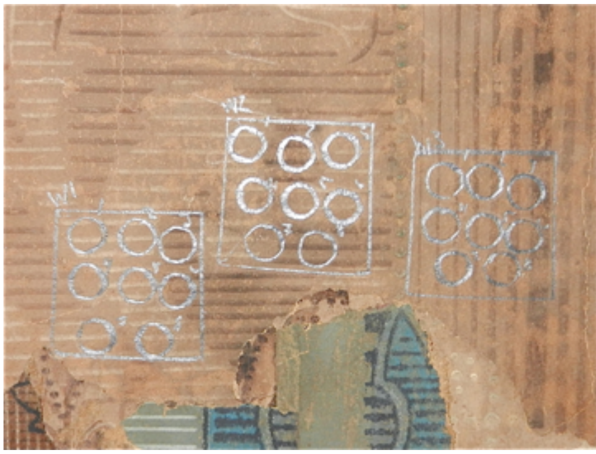
Change in visual characteristics before and after treating



Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	44.57	+11.50	+20.04
Sample #2	41.81	+9.67	+17.21
Sample #3	42.43	+11.24	+19.29
Avg.	42.93	+10.80	+18.85

WALLPAPER 2: WEI T'O

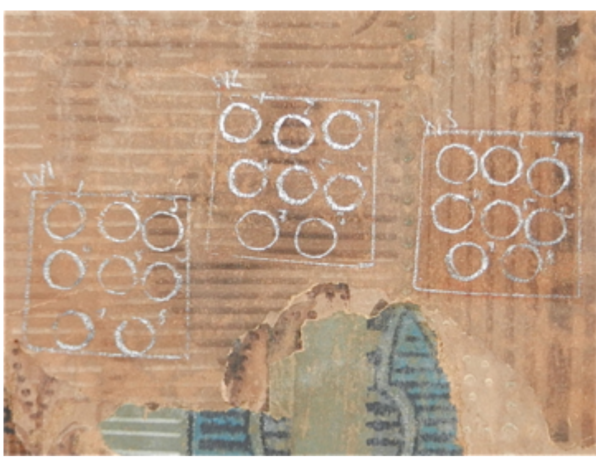


After Surface Cleaning

	L*	a*	b*
Sample #1	45.30	+11.18	+19.71
Sample #2	42.84	+9.57	+16.91
Sample #3	42.74	+10.69	+17.94
Avg.	43.63	+10.48	+18.19
Variance	0.70	-0.32	-0.66
ΔE = 1.01			

After Treating

	L*	a*	b*
Sample #1	42.52	+11.94	+20.42
Sample #2	39.97	+10.12	+17.37
Sample #3	39.43	+11.74	+19.14
Avg.	40.64	+11.27	+18.98
Variance	-2.99	0.79	0.79
ΔE = 3.19			

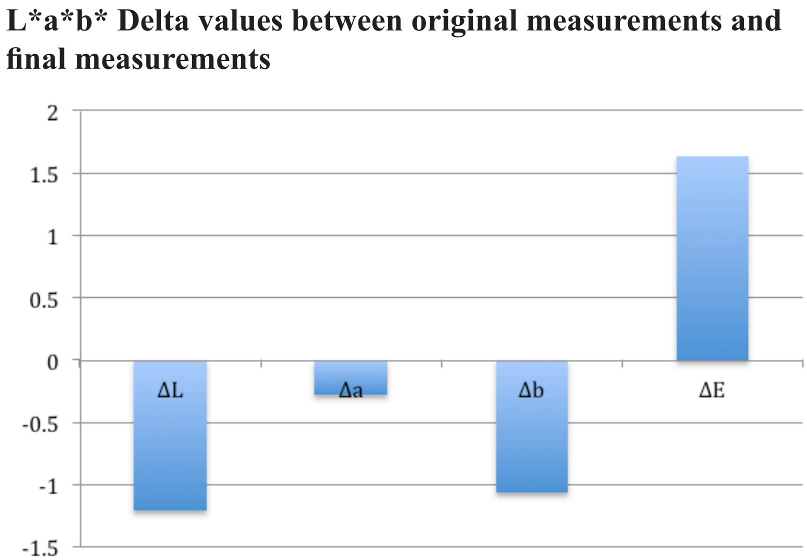


After Surface Cleaning After Treating

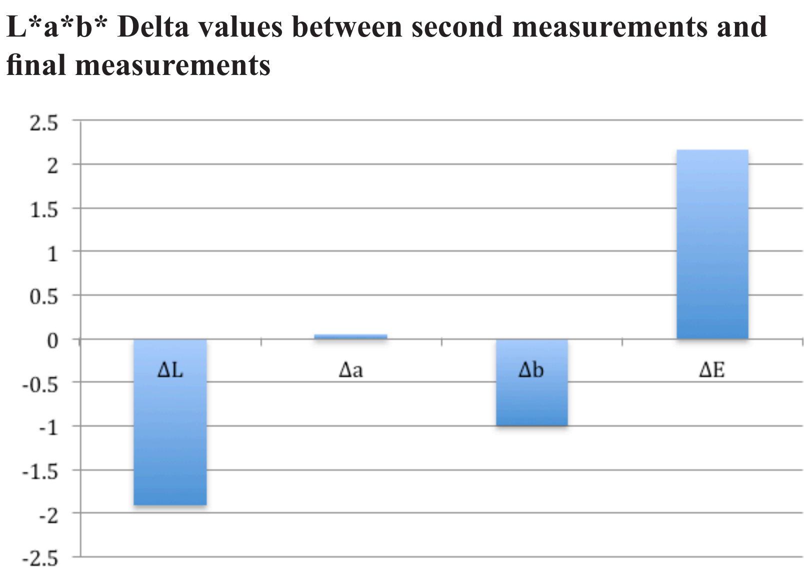
	L*	a*	b*
Sample #1	43.41	+11.42	+19.68
Sample #2	41.14	+9.43	+16.28
Sample #3	40.61	+10.72	+17.42
Avg.	41.72	+10.52	+17.79
Variance	1.08	-0.75	-1.19
ΔE = 1.77			

WALLPAPER 2: WEI T'O

Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= -1.21 (darker), Δa= -0.28 (greener), Δb= -1.06 (bluer)
ΔE= 1.63



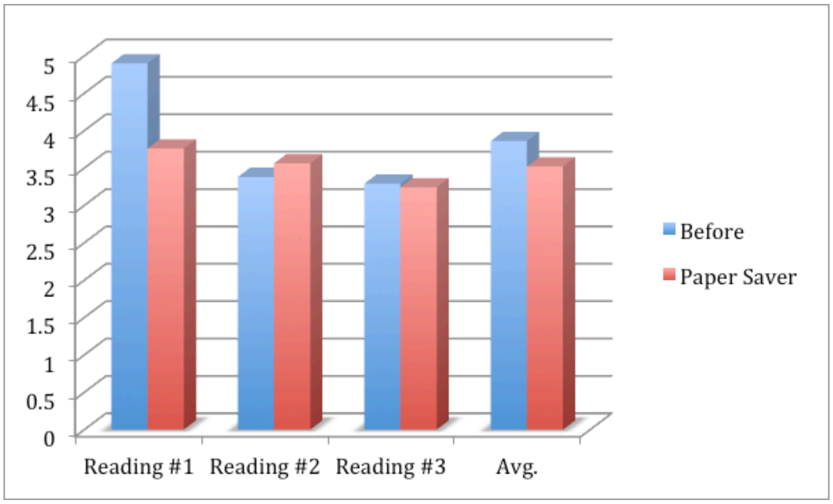
Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= -1.91 (darker), Δa= 0.04 (redder), Δb= -1.00 (bluer)
ΔE = 2.1



WALLPAPER 2: PAPER SAVER

Change in pH values before and after treating

	Before	Paper Saver
Reading #1	4.90	3.76
Reading #2	3.38	3.56
Reading #3	3.29	3.24
Avg.	**3.86**	**3.52**



Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	45.96	+13.38	+22.74
Sample #2	45.57	+13.42	+22.68
Sample #3	45.22	+13.26	+22.45
Avg.	45.58	+13.35	+22.62

WALLPAPER 2: PAPER SAVER

After Surface Cleaning

	L*	a*	b*
Sample #1	46.25	+13.44	+22.60
Sample #2	45.65	+13.29	+22.27
Sample #3	45.25	+13.26	+22.23
Avg.	45.72	+13.33	+22.37
Variance	0.14	-0.02	-0.25
ΔE = 0.29			

After Treating

	L*	a*	b*
Sample #1	46.68	+13.71	+22.13
Sample #2	45.93	+13.41	+22.55
Sample #3	45.59	+13.27	+22.34
Avg.	46.07	+13.46	+22.34
Variance	0.35	0.13	-0.03
ΔE = 0.37			

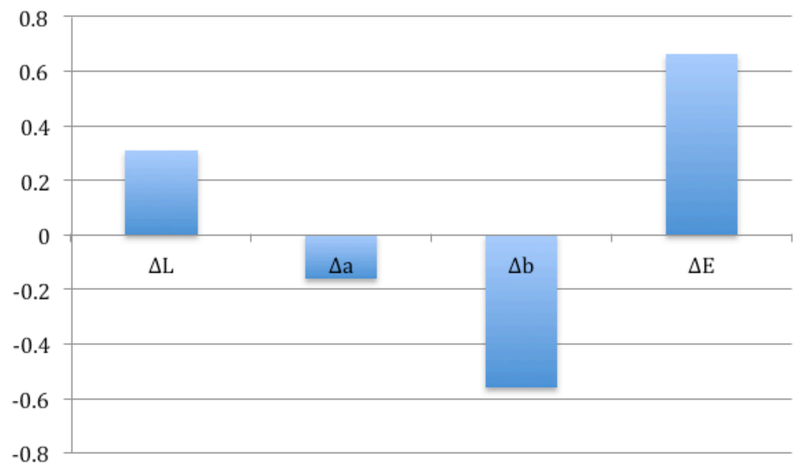
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	46.53	+13.37	+22.43
Sample #2	45.79	+13.19	+22.01
Sample #3	45.35	+13.00	+21.74
Avg.	45.89	+13.19	+22.06
Variance	-0.18	-0.37	-0.28
ΔE = 0.50			

WALLPAPER 2: PAPER SAVER

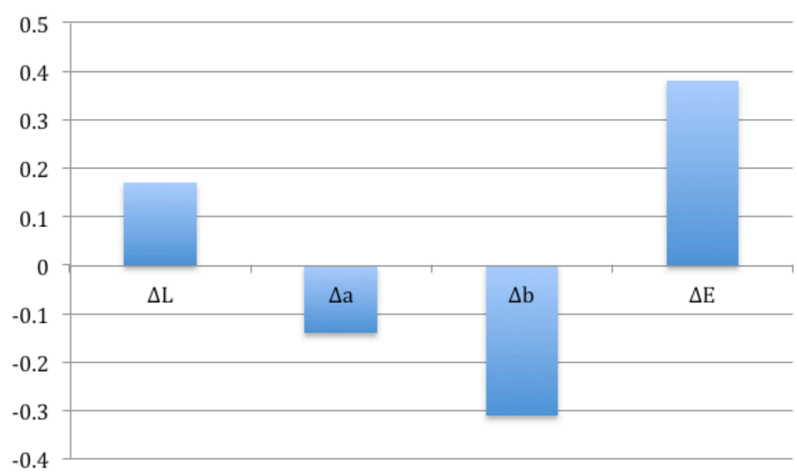
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 0.31 (lighter), Δa= -0.16 (greener), Δb= -0.56 (bluer)
ΔE= 0.66

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 0.17 (lighter), Δa= -0.14 (greener), Δb= -0.31 (bluer)
ΔE = 0.38

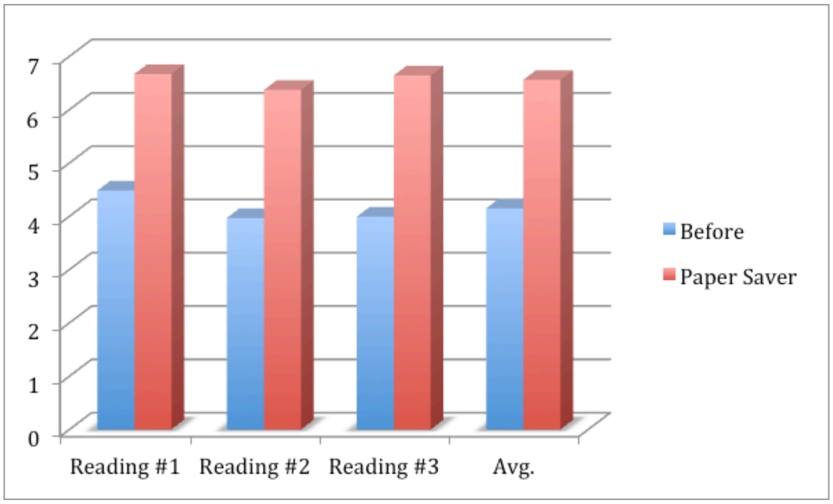
L*a*b* Delta values between second measurements and final measurements



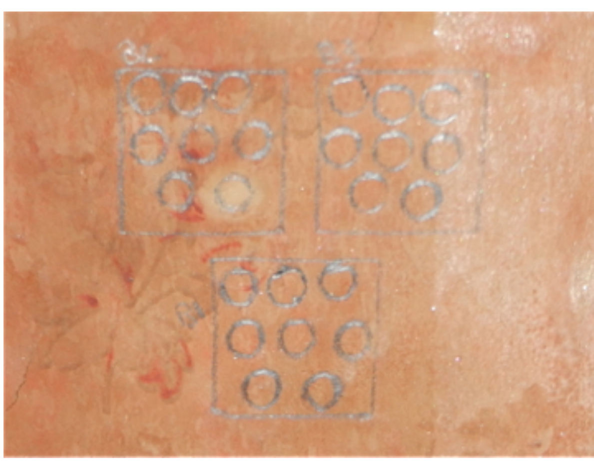
WALLPAPER 3-a: BOOKKEEPER

Change in pH values before and after treating

	Before	Paper Saver
Reading #1	4.48	6.67
Reading #2	3.97	6.37
Reading #3	3.99	6.64
Avg.	**4.15**	**6.56**



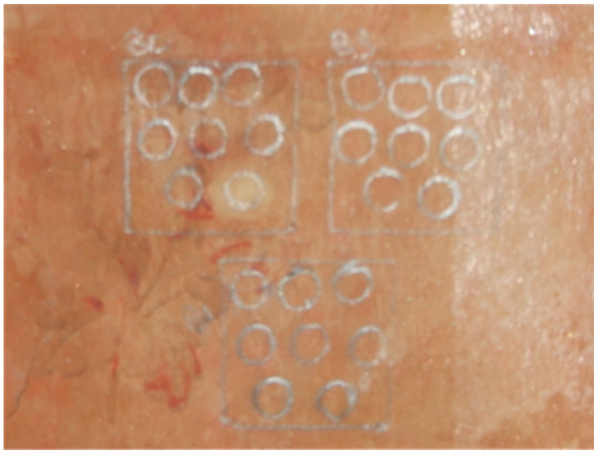
Change in visual characteristics before and after treating



Before Surface Cleaning or Treating

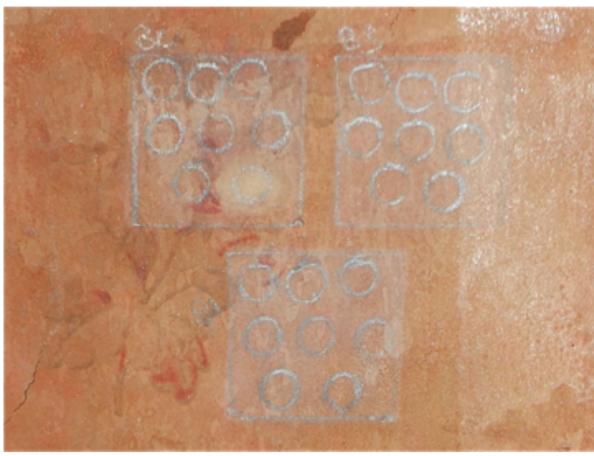
	L*	a*	b*
Sample #1	50.02	+16.16	+26.08
Sample #2	48.94	+15.29	+25.16
Sample #3	53.50	+15.72	+25.93
Avg.	50.82	+15.72	+25.72

WALLPAPER 3-a: BOOKKEEPER



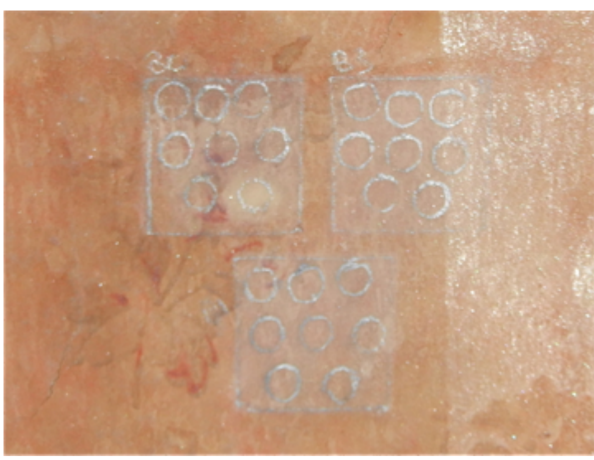
After Surface Cleaning

	L*	a*	b*
Sample #1	48.98	+14.84	+23.67
Sample #2	48.34	+13.85	+22.68
Sample #3	52.86	+15.05	+24.66
Avg.	50.06	+14.58	+23.67
Variance	-0.76	-1.14	-2.05
ΔE = 2.47			



After Treating

	L*	a*	b*
Sample #1	51.78	+12.33	+18.09
Sample #2	50.84	+11.78	+17.82
Sample #3	55.84	+12.55	+18.75
Avg.	52.82	+12.22	+18.22
Variance	2.76	-2.36	-5.45
ΔE = 6.55			



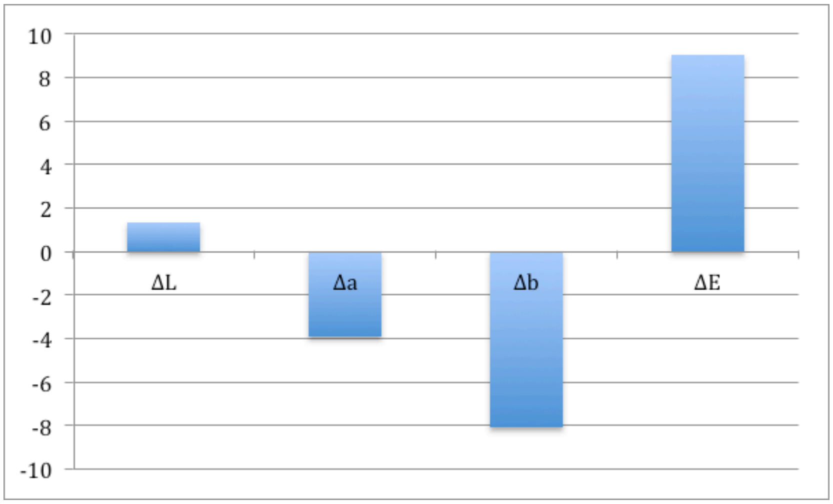
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	51.16	+11.76	+17.36
Sample #2	50.15	+11.48	+17.34
Sample #3	55.05	+12.18	+18.28
Avg.	52.12	+11.81	+17.66
Variance	-0.70	-0.41	-0.56
ΔE = 0.99			

WALLPAPER 3-a: BOOKKEEPER

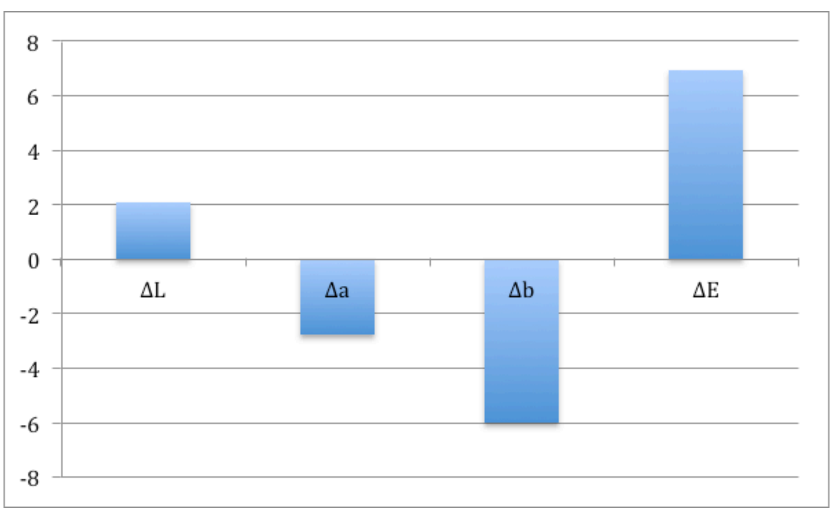
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 1.30 (lighter), Δa= -3.91 (greener), Δb= -8.06 (bluer)
ΔE= 9.05

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 2.06 (lighter), Δa= -2.77 (greener), Δb= -6.01 (bluer)
ΔE = 6.93

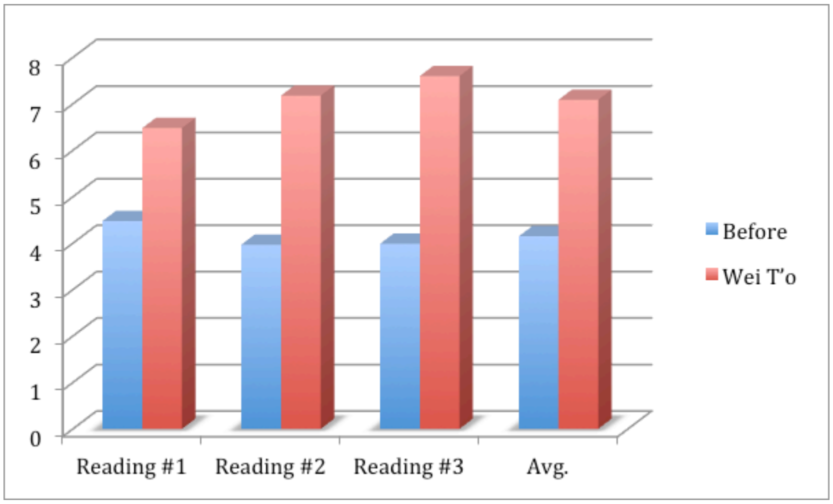
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 3-a: WEI T'O

Change in pH values before and after treating

	Before	**Wei T'o**
Reading #1	4.48	6.48
Reading #2	3.97	7.18
Reading #3	3.99	7.60
Avg.	**4.15**	**7.09**



* Wei T'o testing squares were placed too close to the mantle, making the lower circles somewhat inaccessible with the colorimeter. L*a*b* measurements were taken of the bottom circles by tilting the colorimeter and aiming the aperture at the center of the circles rather than holding it flush against the surface. This may have significantly skewed L*a*b* data, therefore visual monitoring was more heavily relied upon.

Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	52.78	+16.35	+27.71
Sample #2	54.79	+15.04	+24.38
Sample #3	53.64	+14.94	+23.22
Avg.	53.74	+15.44	+25.10

WALLPAPER 3-a: WEI T'O

After Surface Cleaning

	L*	a*	b*
Sample #1	52.14	+15.30	+25.69
Sample #2	54.19	+14.98	+24.10
Sample #3	53.68	+14.16	+21.88
Avg.	53.34	+14.81	+23.89
Variance	-0.40	-0.63	-1.21
Δ*E* = 1.42			

After Treating

	L*	a*	b*
Sample #1	51.02	+15.34	+25.81
Sample #2	53.50	+15.09	+24.13
Sample #3	52.02	+13.99	+21.55
Avg.	52.18	+15.18	+23.83
Variance	-1.16	0.37	-0.06
Δ*E* = 1.22			

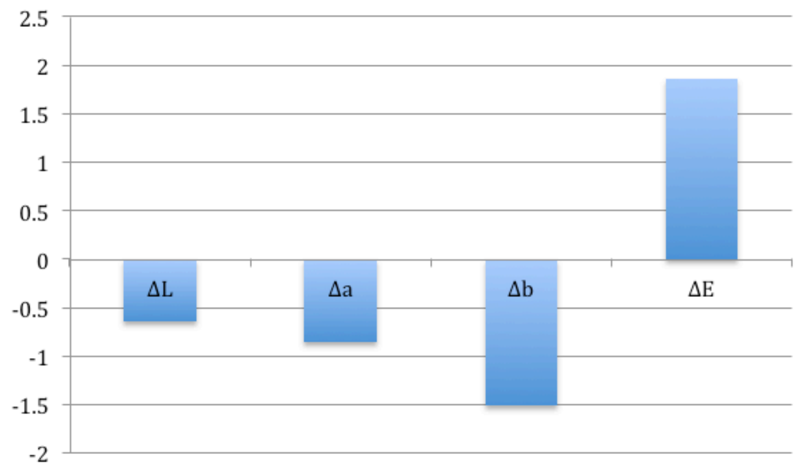
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	51.89	+15.12	+25.32
Sample #2	53.83	+14.85	+23.93
Sample #3	53.55	+13.76	+21.53
Avg.	53.09	+14.58	+23.59
Variance	0.91	-0.60	-0.24
Δ*E* = 1.12			

WALLPAPER 3-a: WEI T'O

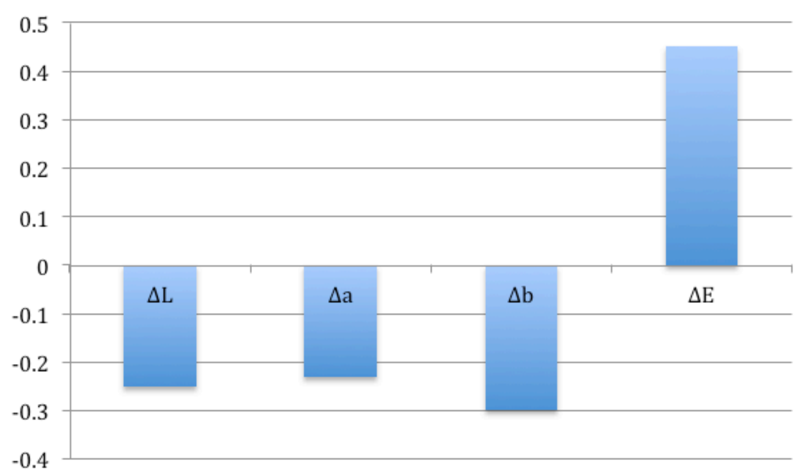
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= -0.65 (darker), Δa= -0.86 (greener), Δb= -1.51 (bluer)
ΔE= 1.86

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= -0.25 (darker), Δa= -0.23 (greener), Δb= -0.30 (bluer)
ΔE = 0.45

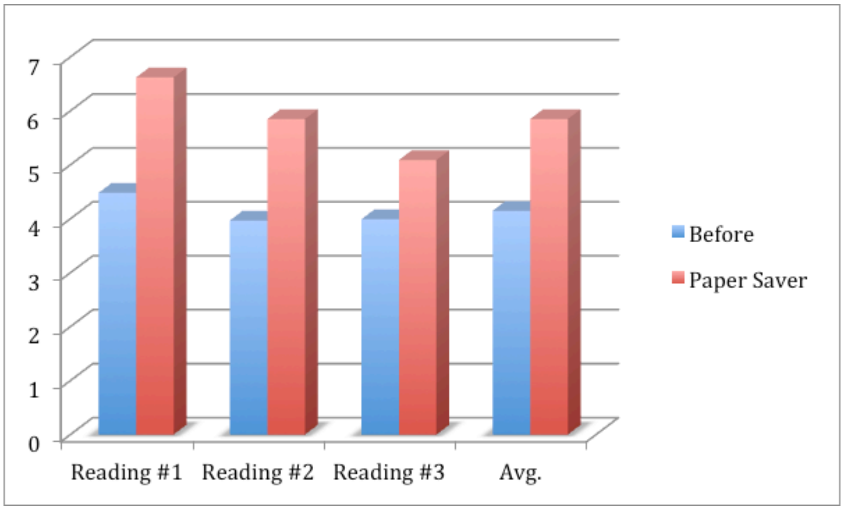
L*a*b* Delta values between second measurements and final measurements



WALLPAPER 3-a: PAPER SAVER

Change in pH values before and after treating

	Before	Paper Saver
Reading #1	4.48	6.62
Reading #2	3.97	5.85
Reading #3	3.99	5.09
Avg.	**4.15**	**5.85**



Change in visual characteristics before and after treating

Before Surface Cleaning or Treating

	L*	a*	b*
Sample #1	55.00	+15.06	+24.72
Sample #2	50.71	+16.26	+25.07
Sample #3	54.63	+14.44	+27.55
Avg.	53.45	+15.25	+25.78

WALLPAPER 3-a: PAPER SAVER

After Surface Cleaning

	L*	a*	b*
Sample #1	54.95	+14.69	+23.89
Sample #2	49.83	+15.43	+23.52
Sample #3	53.40	+13.41	+25.39
Avg.	52.73	+14.51	+24.27
Variance	-0.72	-0.74	-1.51
Δ*E* = 1.83			

After Treating

	L*	a*	b*
Sample #1	56.74	+12.87	+19.63
Sample #2	51.09	+14.97	+22.40
Sample #3	53.98	+13.42	+25.66
Avg.	53.94	+13.75	+22.56
Variance	1.21	-0.76	-1.71
Δ*E* = 2.23			

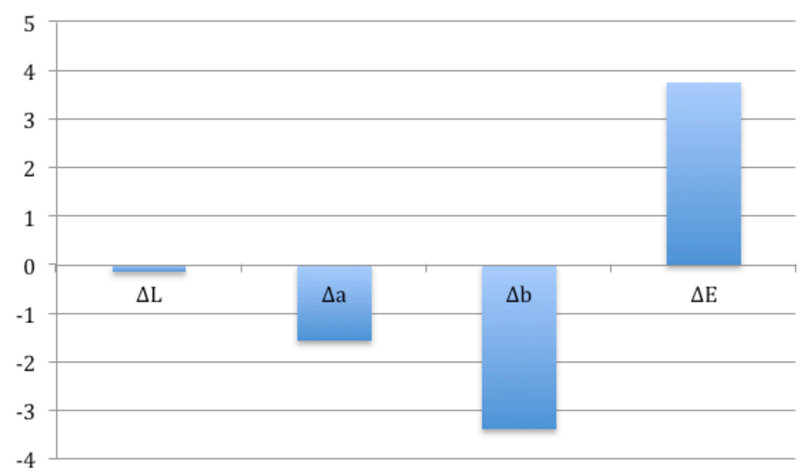
After Surface Cleaning After Treating

	L*	a*	b*
Sample #1	56.13	+12.90	+19.89
Sample #2	50.97	+14.90	+22.27
Sample #3	52.78	+13.20	+25.01
Avg.	53.29	+13.67	+22.39
Variance	-0.65	-0.08	-0.17
Δ*E* = 0.68			

WALLPAPER 3-a: PAPER SAVER

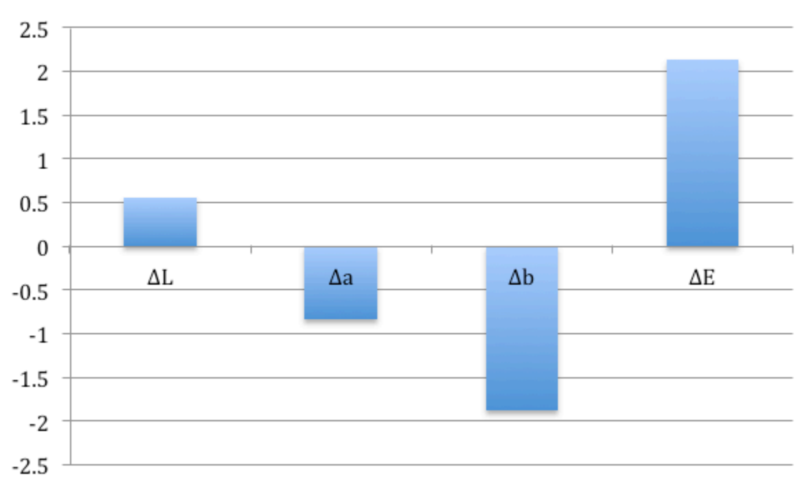
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= -0.16 (daker), Δa= -1.58 (greener), Δb= -3.39 (bluer)
ΔE= 3.74

L*a*b* Delta values between original measurements and final measurements



Variance between L*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 0.56 (lighter), Δa= -0.84 (greener), Δb= -1.88 (bluer)
ΔE = 2.13

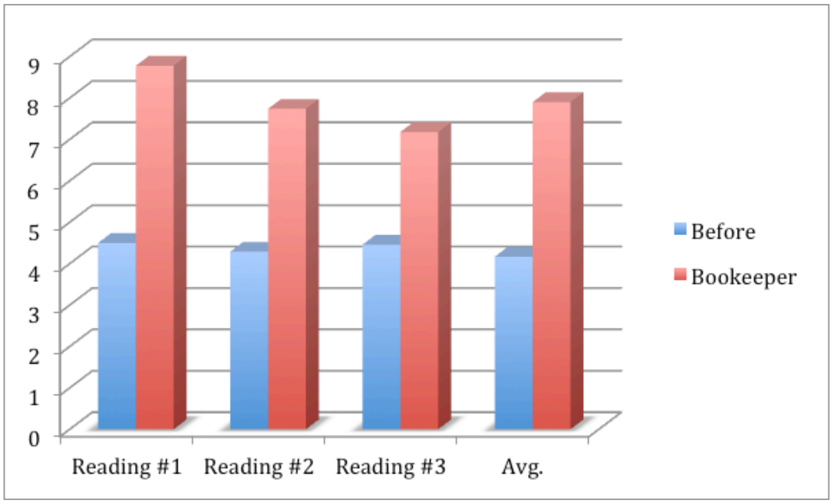
L*a*b* Delta values between second measurements and final measurements



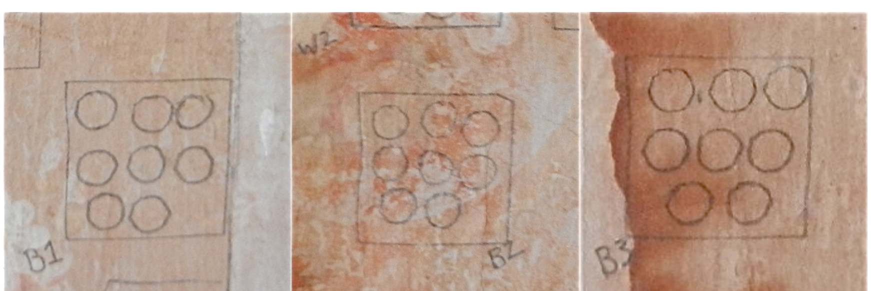
WALLPAPER 3-b: PAPER SAVER

Change in pH values before and after treating

	Before	Bookkeeper
Reading #1	4.50	8.78
Reading #2	4.29	7.74
Reading #3	4.46	7.18
Avg.	**4.17**	**7.90**



Change in visual characteristics before and after treating



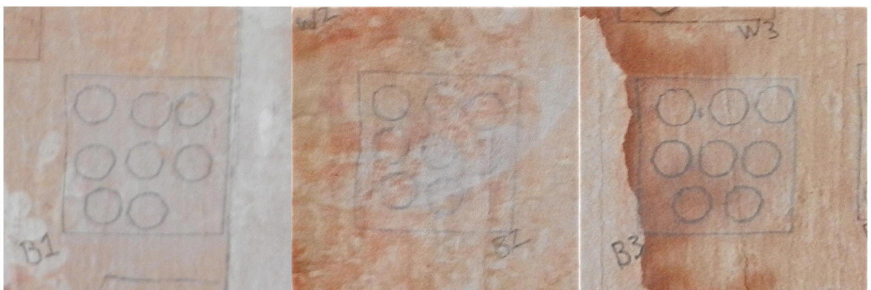
	L*	a*	b*
Sample #1	67.94	+11.70	+19.27
Sample #2	68.83	+14.88	+23.62
Sample #3	59.19	+15.42	+25.00
Avg.	65.32	+14.00	+22.63

Before Surface Cleaning or Treating

WALLPAPER 3-b: PAPER SAVER

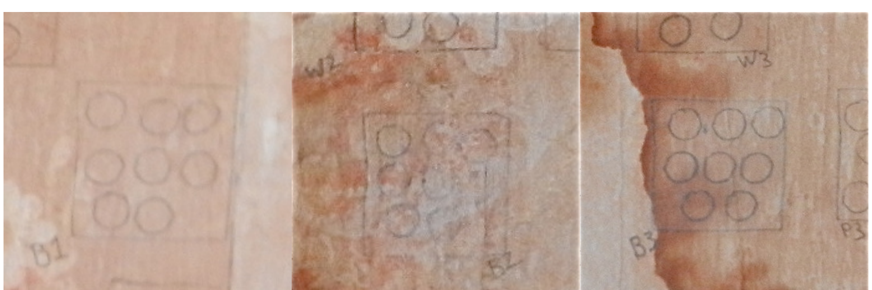
	L*	a*	b*
Sample #1	67.95	+11.36	+18.60
Sample #2	64.73	+13.86	+22.39
Sample #3	59.29	+15.11	+24.36
Avg.	63.99	+13.44	+21.78
Variance	-1.33	-0.56	-0.85
ΔE = 1.67			

After Surface Cleaning



	L*	a*	b*
Sample #1	70.22	+9.63	+14.84
Sample #2	66.33	+12.65	+19.53
Sample #3	62.76	+13.33	+20.11
Avg.	66.43	+11.87	+18.16
Variance	2.44	-1.57	-3.62
ΔE = 4.64			

After Treating



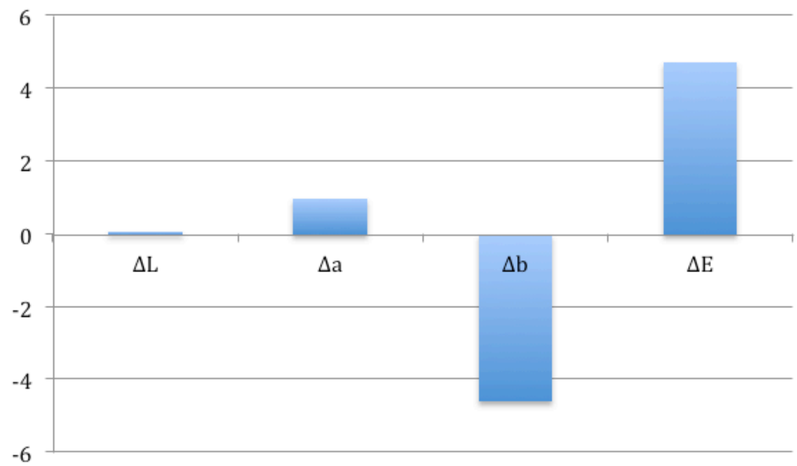
	L*	a*	b*
Sample #1	69.21	+19.80	+15.42
Sample #2	65.38	+12.07	+18.92
Sample #3	61.57	+13.04	+19.73
Avg.	65.39	+14.97	+18.02
Variance	-1.04	3.10	-0.14
ΔE = 3.27			

After Surface Cleaning After Treating

WALLPAPER 3-b: PAPER SAVER

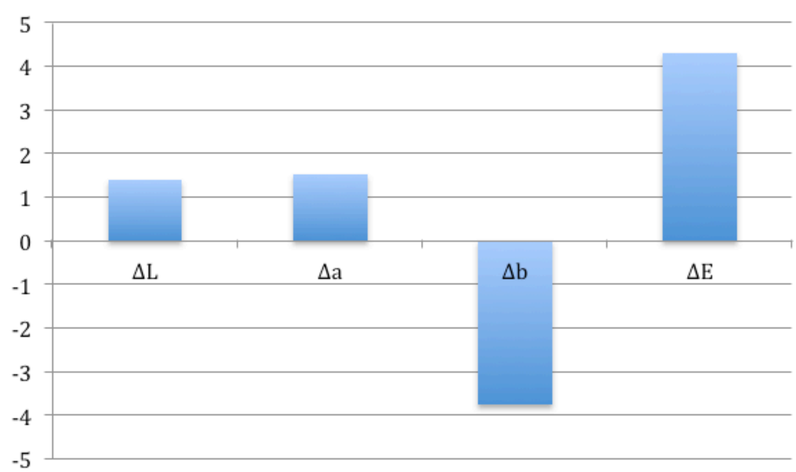
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 0.07 (lighter), Δa= 0.97 (redder), Δb= -4.61 (bluer)
ΔE= 4.71

L*a*b* Delta values between original measurements and final measurements



Variance between l*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 1.40 (lighter), Δa= 1.53 (redder), Δb= -3.76 (bluer)
ΔE = 4.29

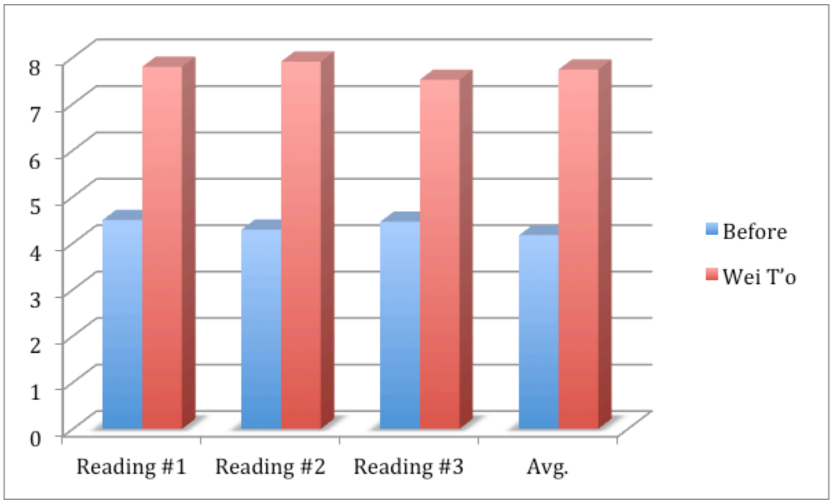
L*a*b* Delta values between second measurements and final measurements



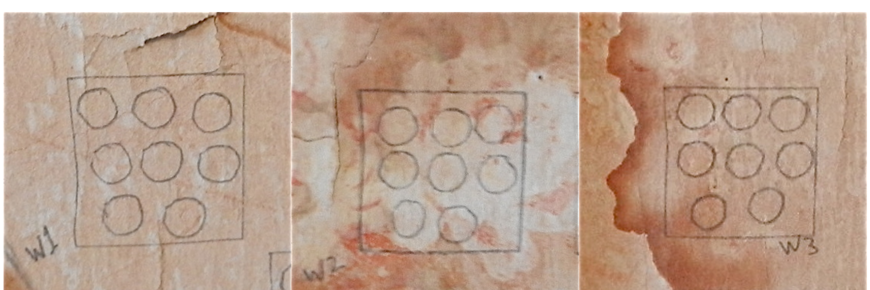
WALLPAPER 3-b: WEI T'O

Change in pH values before and after treating

	Before	Wei T'o
Reading #1	4.50	7.80
Reading #2	4.29	7.91
Reading #3	4.46	7.52
Avg.	**4.17**	**7.74**



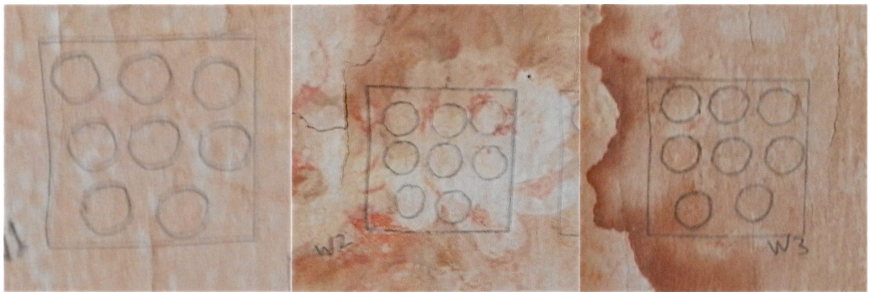
Change in visual characteristics before and after treating



Before Surface Cleaning or Treating

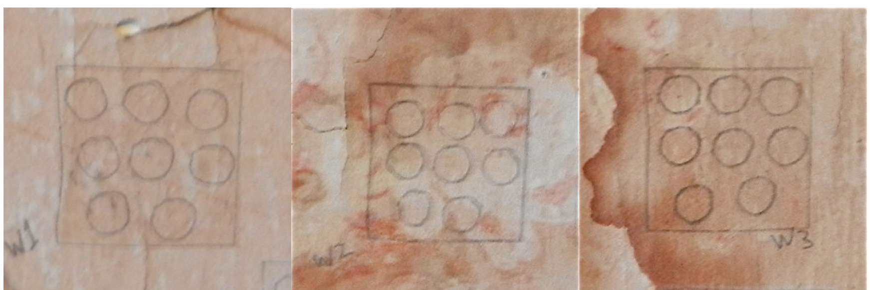
	L*	a*	b*
Sample #1	67.95	+11.97	+19.79
Sample #2	70.93	+11.46	+21.49
Sample #3	64.11	+13.47	+12.86
Avg.	67.66	+12.30	+18.05

WALLPAPER 3-b: WEI T'O



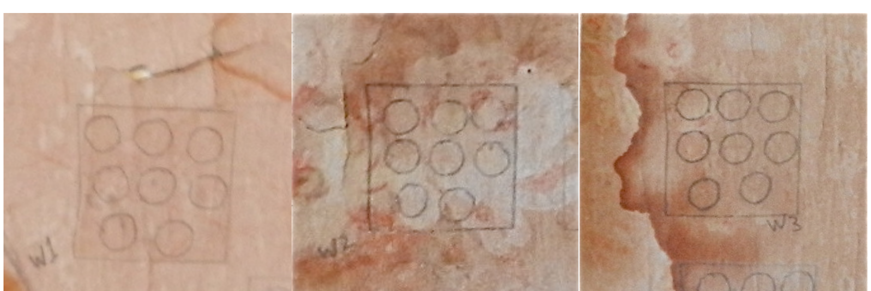
	L*	a*	b*
Sample #1	67.38	+11.70	+19.19
Sample #2	70.71	+11.22	+21.08
Sample #3	63.95	+13.11	+22.10
Avg.	67.35	+12.01	+20.79
Variance	-0.31	-0.29	2.74
Δ*E* = 2.77			

After Surface Cleaning



	L*	a*	b*
Sample #1	65.24	+12.61	+20.90
Sample #2	68.81	+11.55	+21.40
Sample #3	62.91	+14.03	+23.50
Avg.	65.65	+12.73	+21.93
Variance	-1.70	0.72	1.14
Δ*E* = 2.17			

After Treating



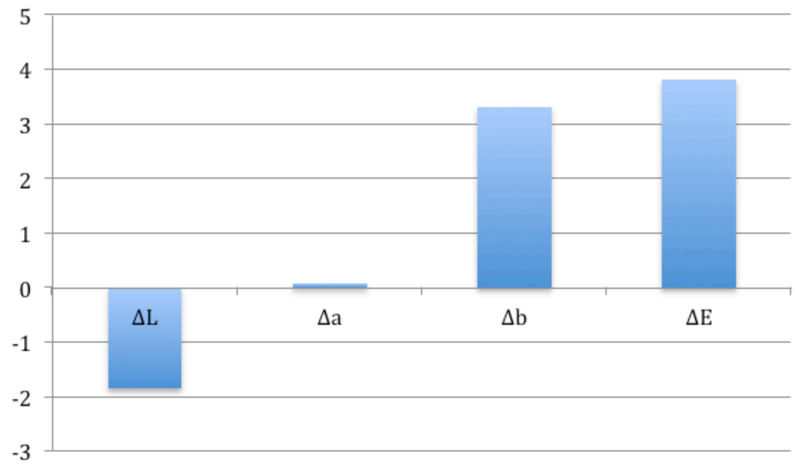
	L*	a*	b*
Sample #1	65.37	+12.43	+20.57
Sample #2	68.70	+11.36	+21.16
Sample #3	63.34	+13.31	+22.34
Avg.	65.80	+12.37	+21.36
Variance	0.15	-0.36	-0.57
Δ*E* = 0.69			

After Surface Cleaning After Treating

WALLPAPER 3-b: WEI T'O

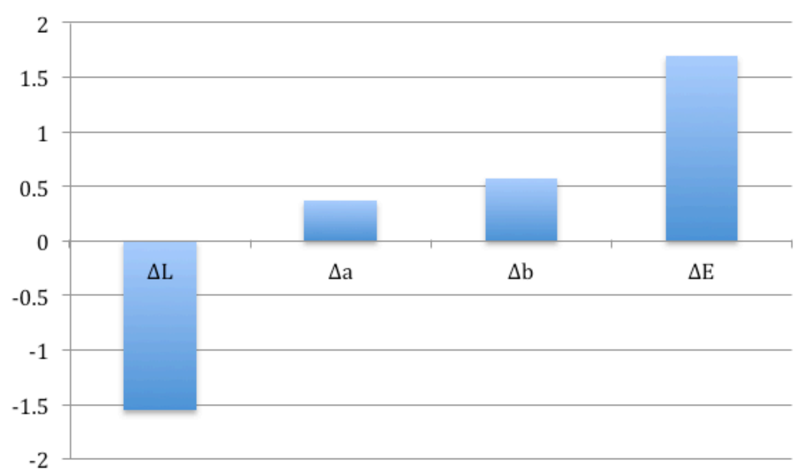
Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= -1.86 (darker), Δa= 0.07 (redder), Δb= 3.31 (yellower)
ΔE= 3.80

L*a*b* Delta values between original measurements and final measurements



Variance between l*a*b* after initial cleaning and after treatment and cleaning:
ΔL= -1.55 (darker), Δa= 0.36 (redder), Δb= 0.57 (yellower)
ΔE = 1.69

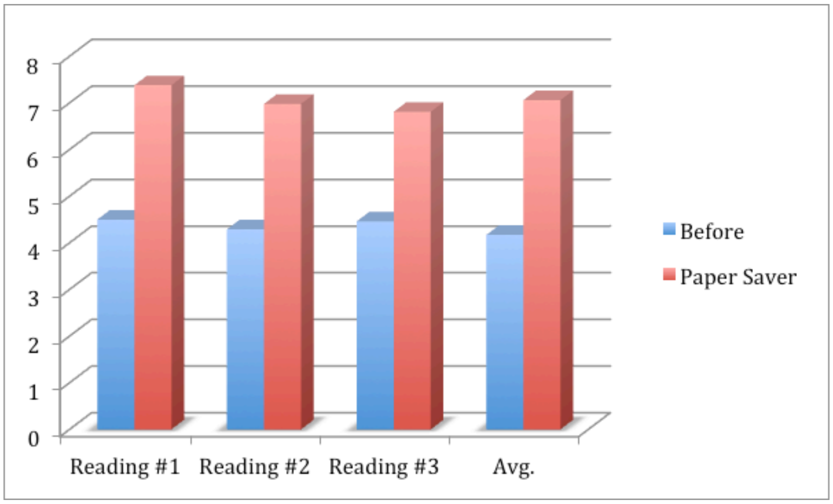
L*a*b* Delta values between second measurements and final measurements



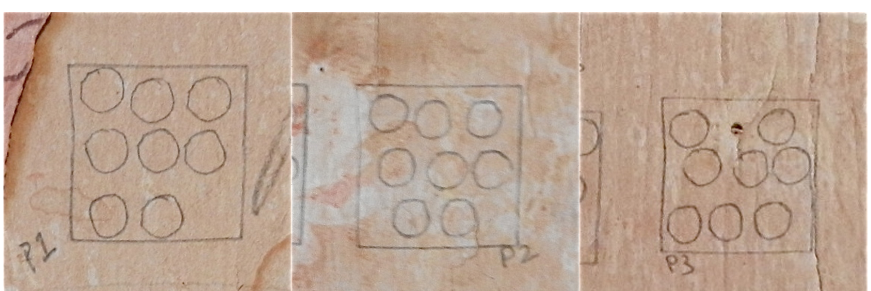
WALLPAPER 3-b: PAPER SAVER

Change in pH values before and after treating

	Before	**Paper Saver**
Reading #1	4.50	7.38
Reading #2	4.29	6.98
Reading #3	4.46	6.81
Avg.	**4.17**	**7.06**



Change in visual characteristics before and after treating



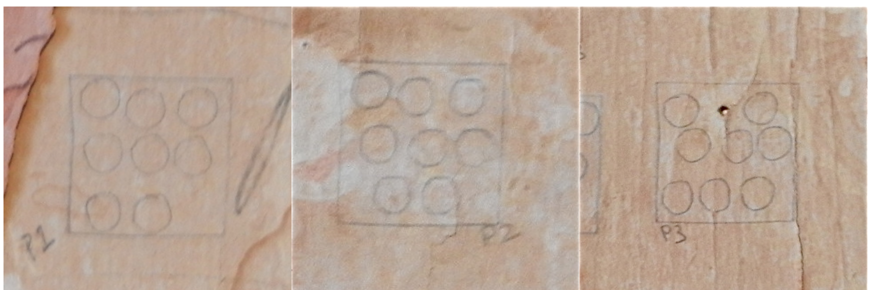
	L*	**a***	**b***
Sample #1	68.04	+12.07	+20.97
Sample #2	69.24	+11.04	+20.18
Sample #3	66.44	+12.86	+22.08
Avg.	67.91	+11.99	+21.08

Before Surface Cleaning or Treating

WALLPAPER 3-b: PAPER SAVER

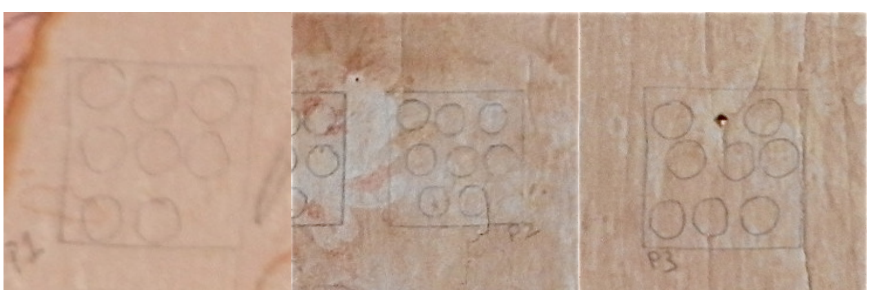
	L*	a*	b*
Sample #1	67.59	+11.70	+20.16
Sample #2	69.41	+10.80	+19.74
Sample #3	65.99	+12.46	+21.32
Avg.	67.66	+11.65	+20.41
Variance	-0.25	-0.34	-0.67
Δ*E* = 0.79			

After Surface Cleaning



	L*	a*	b*
Sample #1	68.21	+11.15	+18.99
Sample #2	69.29	+10.29	+18.73
Sample #3	67.53	+11.97	+20.26
Avg.	68.34	+11.14	+19.33
Variance	0.68	-0.51	-1.08
Δ*E* = 1.37			

After Treating

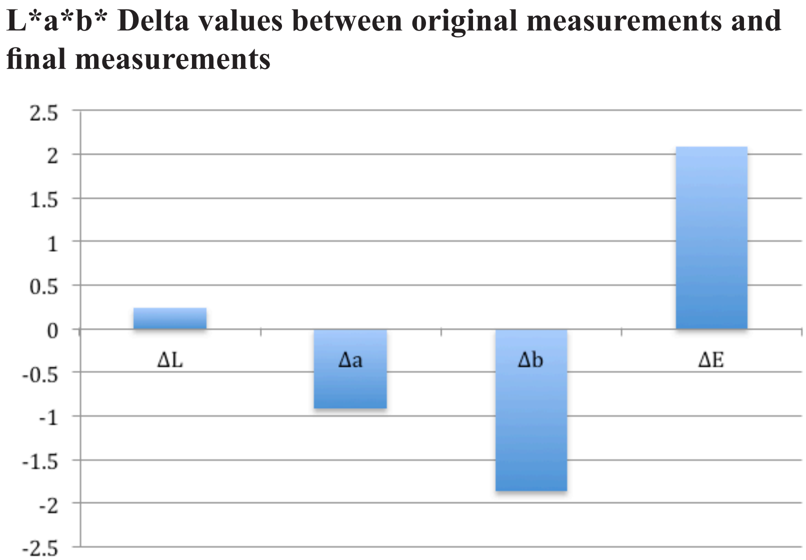


	L*	a*	b*
Sample #1	68.06	+11.12	+18.95
Sample #2	69.27	+10.13	+18.45
Sample #3	67.13	+11.97	+20.26
Avg.	68.15	+11.07	+19.22
Variance	-0.19	-0.07	-0.11
Δ*E* = 0.23			

After Surface Cleaning After Treating

WALLPAPER 3-b: PAPER SAVER

Variance between L*a*b* values before cleaning and treating and after cleaning and treating with Bookkeeper:
ΔL= 0.24 (lighter), Δa= -0.92 (greener), Δb= -1.86 (bluer)
ΔE= 2.09



Variance between l*a*b* after initial cleaning and after treatment and cleaning:
ΔL= 0.49 (lighter), Δa= -0.58 (greener), Δb= -1.19 (bluer)
ΔE = 1.41